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Air Pollution Potential in Arizona

by

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ABSTRACT

Background and urban levels of present air quality are presented for reference. Wind speeds and mixing heights, the important parameters in air pollution potential, are discussed for the state. Frequencies of wind direction and average velocities are used in Gaussian plume models to evaluate air pollution potential at several locations in the state. Detailed air shed modeling to give spatial and temporal distributions of atmospheric concentrations are discussed for the Salt River Valley, the location of Phoenix, Arizona.

In general the lower wind speeds in the southwestern desert areas of the state lead to higher predicted yearly average concentrations of potential pollutants. However, the northeastern plateau has the highest frequency of prolonged low level afternoon inversions. Normally the air in Arizona is clean and visibility is extremely high. Small amounts of pollutants in the air can lead to discoloration and reduced visibility, although concentrations are far below air quality standards.

Maps of air pollution potential are presented in an appendix as overlays on U.S. Geological Survey maps. The use of these overlays for other locations in the state is discussed.

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AIR POLLUTION POTENTIAL IN ARIZONA

Neil S. Berman

INTRODUCTION

Air pollution potential has been defined as "the inability of the atmosphere to disperse and dilute contaminants which may be emitted into it". On a local scale unacceptable levels of pollution may mean one level in a certain location and a quite different level in another. Air quality in Arizona is often very visible. The plume from a stack is visible in the early morning when the atmosphere is stable. The urban haze in the afternoon can be seen 50 miles north of Phoenix. However, at ground level the concentrations of pollutants are very low in these two cases. We can see small quantities of pollutants in the atmosphere because the present air quality is good. Atmosphere conditions and topography in Arizona generally lead to visibilities in excess of 50 miles.

Although air pollution potential does not depend on current levels of pollutants, this discussion will start with present urban and background levels. Then the geographical and meteorological factors important in the evaluation of air pollution potential will be presented. The final part of the presentation describes the use of models in the prediction of pollution potential.

Airzona is divided geographically into three regions: the northeast, a part of the Colorado Plateau; the Mexican Highland region cutting a diagonal path from the northwest to southeast; and the southwest Sonora desert. Most of the recent growth of Arizona has occurred in the southwestern area where the large urban areas are located. In the mountain region the interaction of man and wildlands is most intense. The permanent population density of 5 persons per square mile swells manyfold during the

seasons of recreational activity. It will be important to remember these locations in the discussion that follows.

Present Air Quality

Measurements of total suspended particulates and sulfur dioxide have been taken at many locations in the state of Arizona over a period of years. Other pollutants such as carbon monoxide, hydrocarbons, nitrogen oxides and oxidants are only measured at urban sites in Phoenix and Tucson. Standard techniques for nitrogen oxides and oxidants have only been available for a short time so the interpretation of past data for these contaminants is questionable.

The generally accepted method for the measurement of suspended particulate matter is the net weight of material collected on a 20 by 25-centimeter glass fiber filter through which approximately 2200 cubic meters of air have been drawn over a 24-hour period. At least one such determination each six days for a year is necessary to obtain the yearly average. Figure 1 shows the yearly average in Arizona for 1973 in the commonly accepted units of micrograms of particulates per cubic meter of air. These data and the data for other pollutants were obtained from the Arizona State Department of Health services (1974) and the U. S. Environmental Protection Agency (1974). For particulates the U. S. national background sites average is 30 micrograms per cubic meter and the total U. S. average is 68. The Arizona state standard is 60 (all based on the yearly average).

The Arizona background varies from approximately 30 micrograms per cubic meter in the plateau and mountains of the northern part of the state to approximately 50 micrograms per cubic meter in the southern deserts. Grand Canyon National Park registers 22, Montezuma's Castle National Monument 28, Petrified Forest National Monument 26, and Organ Pipe National Monument

Total Suspended Particulates

1973 Annual Average (micrograms / cu. meter)

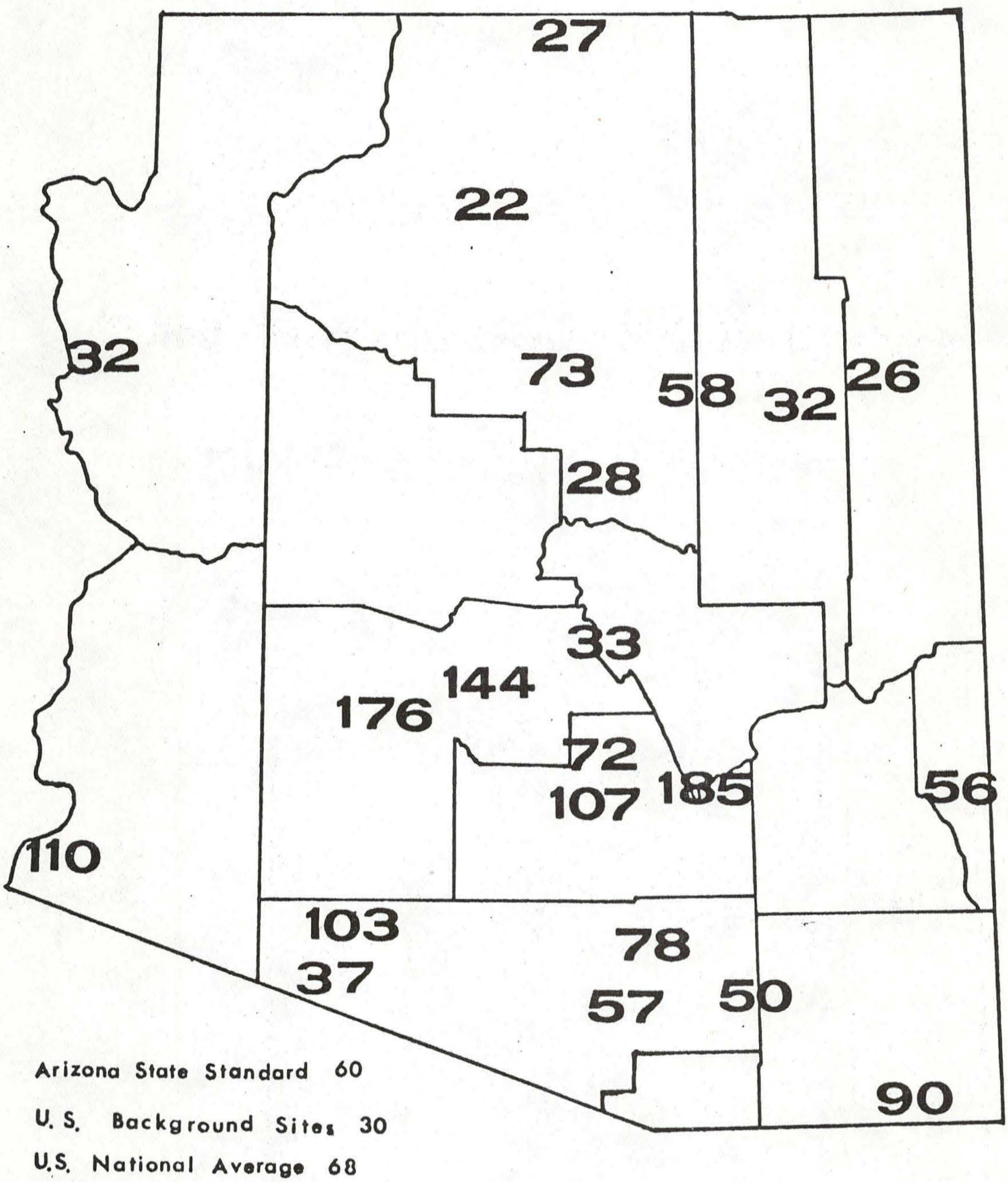


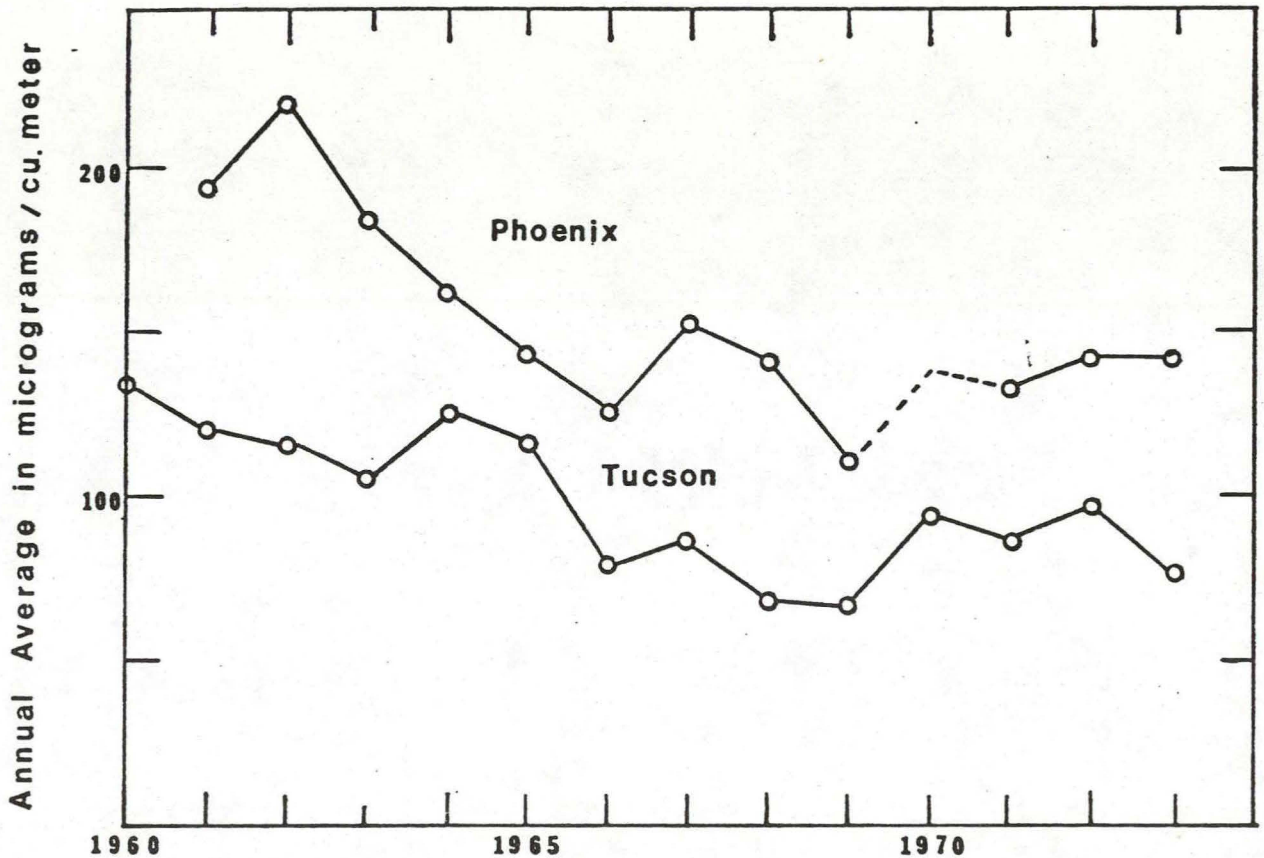
Figure 1. Total suspended particulates in Arizona on a map showing county boundaries and typical annual average concentrations at the approximate measurement location. Units are micrograms of solids per cubic meter of air.
*See Appendix Table A-1 for city names for data on this map.

37. Particulates above these background levels are locally generated and annual averages are functions of the urban size and activity and the local wind speeds. More will be said about wind speed later. Here it is noted that the desert areas have much lower wind speeds than the mountain and high plateau regions.

Significant trends toward decreased levels of suspended particulates as shown in figure 2 have been evident in the major urban areas of the state in spite of the rapid growth of population. Among the reasons for the decline are paving of roads and decreases in agricultural and building activity near the monitoring sites. Phoenix remains quite high, although not unreasonable for a urban area of 1.2 million people. Even small urban areas lead to increases in the particulate count above the background as shown in figure 3. The valley type of desert areas show consistantly higher values than the mountain group. Some very high values for small towns are due to the large amount of industrial or mining activity in the area.

Very extensive monitoring of sulfur dioxide in the air is carried out in Arizona. Figure 4 shows the average concentrations at typical sites. Except for copper mining areas and nearby locations the measurements are below the U. S. background site average of 10 micrograms per cubic meter. The locations marked with the triangles each have several monitors and concentrations are high in certain directions only. The U. S. national average is 25 and the state standard 50. Note that Phoenix with 9 and Tucson with 7 are not much different from the Grand Canyon with 6 and that mining activities in the state show up only locally.

The other contaminants are significant in urban air pollution and have significant variations with the diurnal cycles of sunlight, automobile traffic and winds. Annual averages are generally near background



Annual Average Total Suspended Particulates in Major

Urban Areas of Arizona

Figure 2. Trend of total suspended particulates at stations in Phoenix and Tucson which have a record of data for a number of years. Concentration units are micrograms per cubic meter.

Annual Average Suspended Particulates as a Function of Urban Size

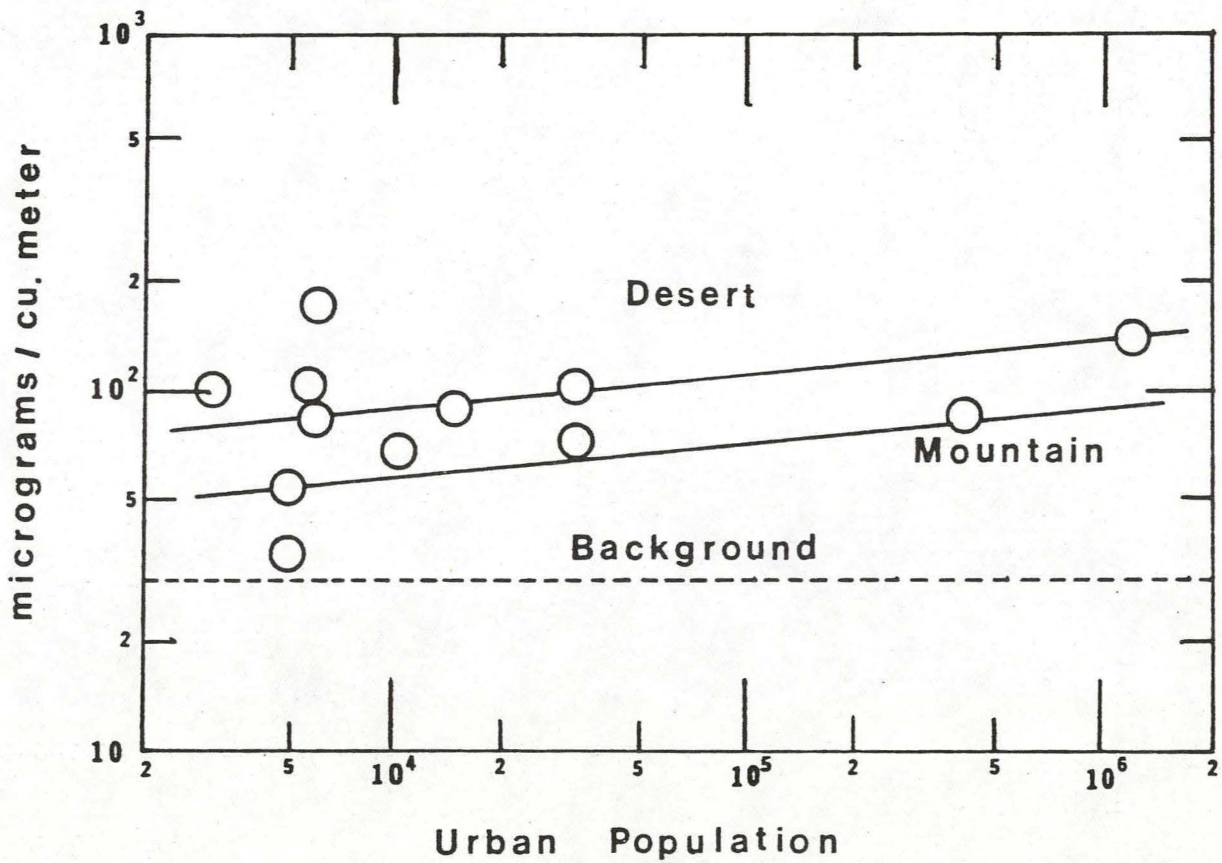
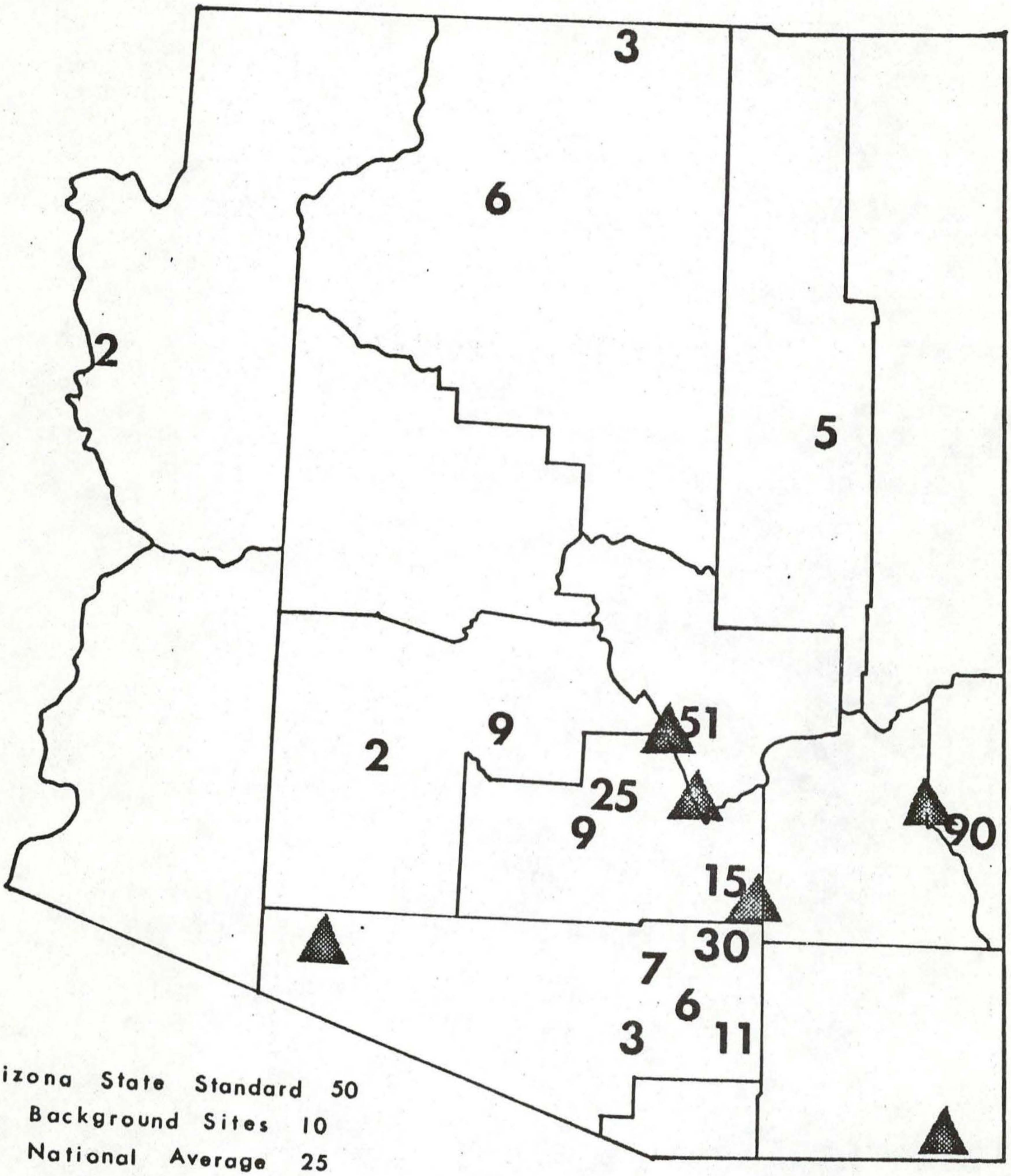


Figure 3. Total suspended particulates as a function of Urban population on log-log scales. Concentration units are micrograms per cubic meter.

Sulfur Dioxide

1973 Annual Average (micrograms / cu. meter)



Arizona State Standard 50
U.S. Background Sites 10
U.S. National Average 25

▲ Copper Mining—High Local Concentrations

Figure 4. Sulfur dioxide concentrations in Arizona. Typical annual average concentration in micrograms per cubic meter are shown at approximate measurement locations. Triangles are copper mining areas.

even in the urban areas except for NO_2. However, carbon monoxide concentrations in parts of Phoenix exceed the 8 hour standard of 10 parts per million (11,456 micrograms per cubic meter) in the late evening when wind speeds are low in the winter months. Over 95% of the carbon monoxide is generated by automobiles. Hydrocarbons and nitrogen oxides are also high during the times of high carbon monoxide concentrations but the amounts are far below the standards. Oxidant concentrations can be high from noon to 4 p.m. when wind speeds are low. The oxidants are produced by reactions involving nitrogen oxides, hydrocarbons, air water vapor and sunlight. The necessary concentrations or amounts of these constituents to produce oxidant concentrations approaching the standards are present on several days in spring and summer in Phoenix and Tucson. Aerosols produced by these same reactions even in small concentrations drop the visibility markedly, however, so little amounts are easily noticeable. These aerosols and nitrogen dioxide are responsible for the urban haze which spreads over considerable areas at times.

The mean visibility in the Petrified Forest National Park in 1973-1974 was found to be 70 miles (Roberts et al. 1974) during the daylight hours. During the year the best visibility occured in winter with an average 78 miles with fall and spring giving 70 miles and summer 60 miles. Nitrogen dioxide concentrations in the Petrified Forest average 13 micrograms per cubic meter on an annual basis, but the highest 24 hour average was 53 in 1973. Using the analysis presented by Robinson (1968) it can be shown that an observer looking at the horizon will definetely see a brownish coloration due to the nitrogen dioxide when the visibility is 70 miles and the nitrogen dioxide concentration is at the maximum. Such conditions of high visibility exist in all parts of Arizona including the urban areas. In Phoenix the NO_2 discoloration is observable in the early morning in the western part of the

Salt-Gila River valley when the visibility is high and small amounts of NO_2 remain in the air from the previous day's traffic. In most other urban areas of the U. S. normal visibilities are much lower and higher concentrations of NO_2 are needed to discolor the air.

Another consequence of the urban atmosphere is the absence of oxidants at night when the reverse of the day reactions occur. Although few measurements have been made in rural areas, we suspect that a small level of oxidants persists as a background at all times. The much different diurnal pattern of nitrogen oxides and oxidants in the urban atmosphere is just beginning to be studied.

Present air quality in Arizona is therefore generally quite good with respect to air quality standards. Only local problems exist and there is a definite improvement trend. Improvements in the aesthetic appearance of the air require different standards than the present ones related to health.

AIR POLLUTION POTENTIAL

Important Parameters

The concentration of pollutants in the local atmosphere is governed by the amount of emissions and the dilution of these emissions by mixing and removal in the atmosphere. If the emissions are at ground level in relatively flat terrain, the problem can be related to mixing in a box whose height is set by the mixing characteristics of the atmosphere and the horizontal dimensions determined by the wind speed. The smaller the box, the higher the concentration of pollutant will be.

Atmospheric conditions are not predictable in advance so we can only deal with probabilities based on past experience. Any given combination of atmospheric conditions will never occur again in precisely the same way.

Thus air pollution potential deals with maximum expected concentrations, averages or typical exposures and large deviations from these can be expected.

First we will define and discuss conditions of importance in the prediction of air pollution potential in Arizona: Wind speed and wind direction; and atmospheric conditions responsible for mixing height.

Wind Speed and Direction

Records of wind speed and direction are not abundant for Arizona. Ideally we would like to have data on wind speed, direction and atmospheric stability in the form of joint probability distributions. Such information is available from the National Climatic Center for six cities in Arizona. However, we cannot extrapolate very far from the location of the measurement and any use of the data requires familiarity with local topography.

Wind direction probabilities based on at least one year's data of hourly measurements are more readily available. In general southwest winds are most frequent across the entire state. Figure 5 shows the average wind speed at several locations and the direction second most frequent. Wind speeds are higher in the northern part of the state compared to the south. The direction shown on the map often corresponds to the night drainage wind.

Frequencies of wind direction are reported for 16 compass directions or sectors. If we compare the wind direction frequency for the three sectors in the south westerly direction for the northern and southern parts of the state, we find that between 30 and 40 percent of the time winds are from these directions in the north compared to approximately 20 percent in the south. Definite drainage winds account for 30 to 40 percent of the frequency distribution in the south but only 10 to 20 percent in the north. Terrain influenced upslope winds appear in the frequency distributions in the south also. Therefore we conclude that the terrain influence on local

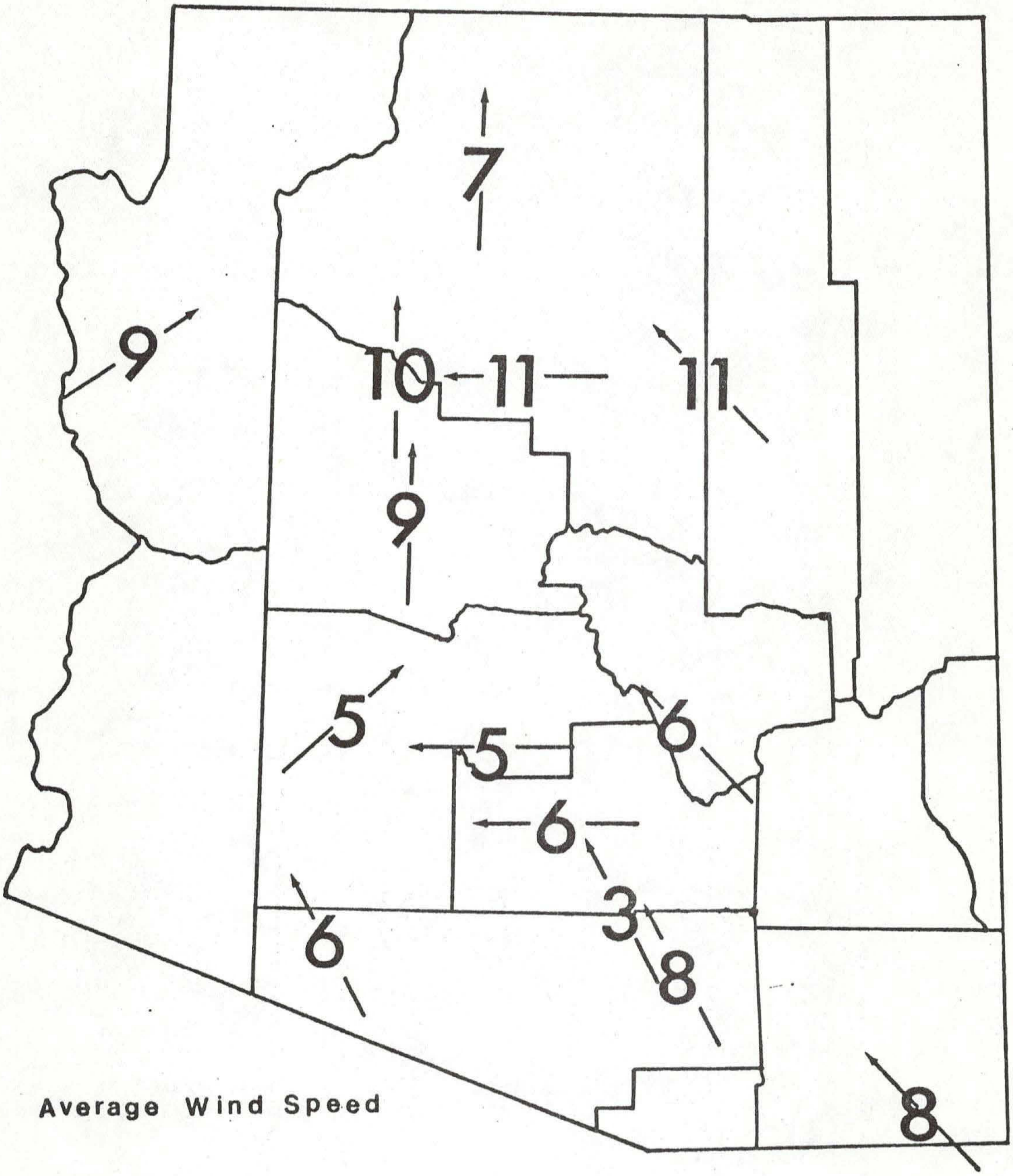


Figure 5. Annual average wind speeds in Arizona.
* See Appendix Table A-3 for complete data.

wind climatology of Arizona cities is much more important in the southern desert part of the state than in the mountain or plateau regions of the north. This is generally attributed to the higher elevation of the north and the increased contact with the prevailing winds characteristic of this higher elevation. Some modifications would have to be made to these observations for some rugged areas of the state like the rim area.

In the river valley areas of the state a definite drainage wind develops at night. Cold air from the higher elevations flows down the slopes and down the river also. In Phoenix these drainage winds as shown on figure 6 develop between 6 and 8 p.m. in the winter and last until noon the next day. In the summer only poorly developed drainage winds form between 2 and 4 a.m. and last about 8 hours. Daytime heating of the valley floor and the slopes leads to upslope and upriver winds in the afternoon. Again in Phoenix as shown on figure 7 these upslope winds start at noon and last until six in winter and until midnight in summer. The winter afternoon winds are light, poorly developed and highly affected by low mountains while the summer afternoon winds are much stronger and blow over the low hills and mountains. Tucson winds are similarly influenced by the terrain and have a somewhat higher speed at the airport compared to Phoenix. Different spots in Phoenix and Tucson show widely varying wind patterns with average velocities ranging from 3 to 8 miles per hour at locations less than 10 miles apart. Obviously accurate predictions of air quality are possible only after detailed studies of a particular location. Wind frequencies and speeds at a single point can only provide a qualitative basis for comparison for long term averages.

Mixing Height

Holzworth (1972) has compiled data on mixing heights and wind speeds for the United States. The wind speed graphs for Arizona are misleading and

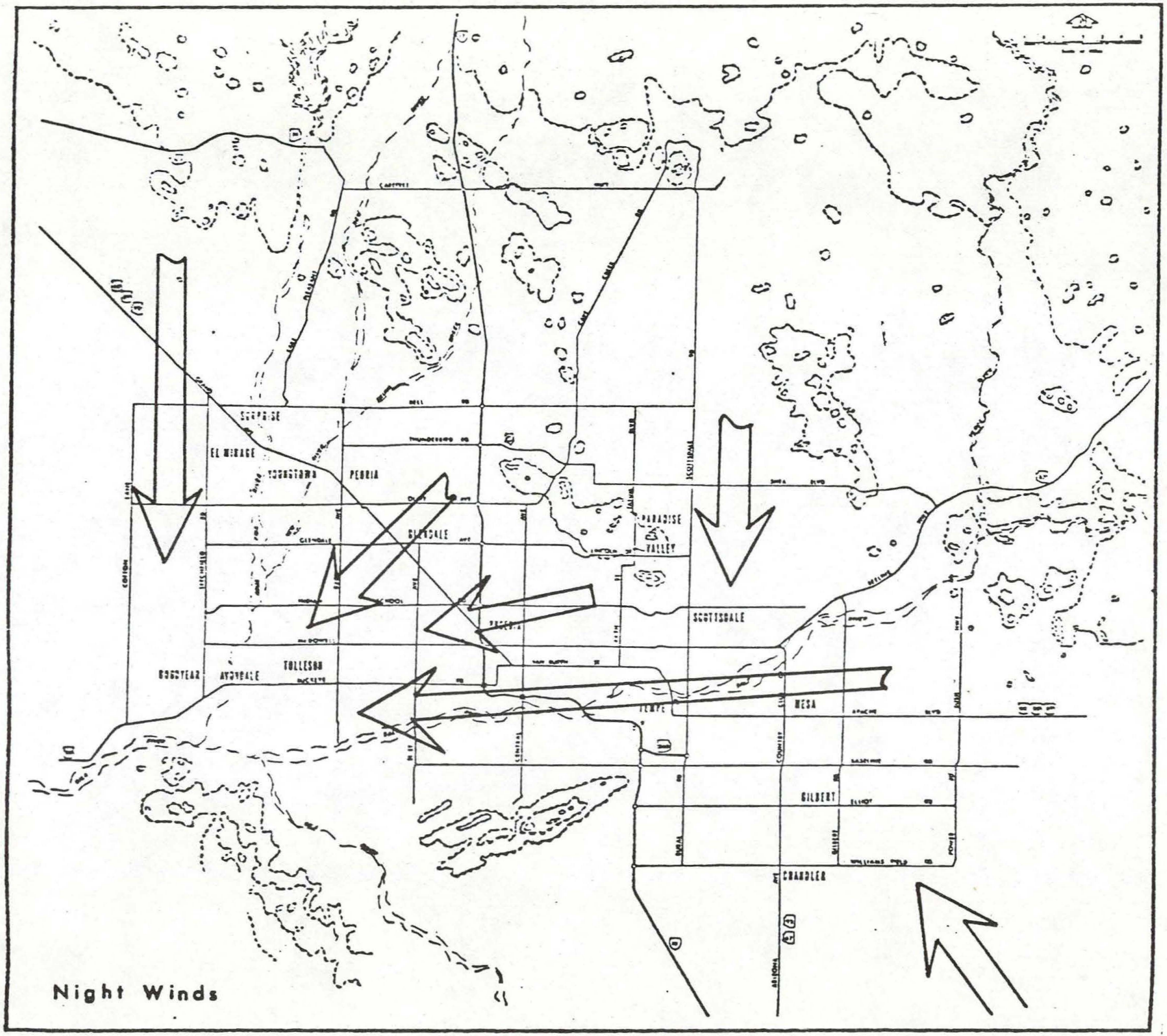


Figure 6. Drainage winds in the Salt River Valley near Phoenix.

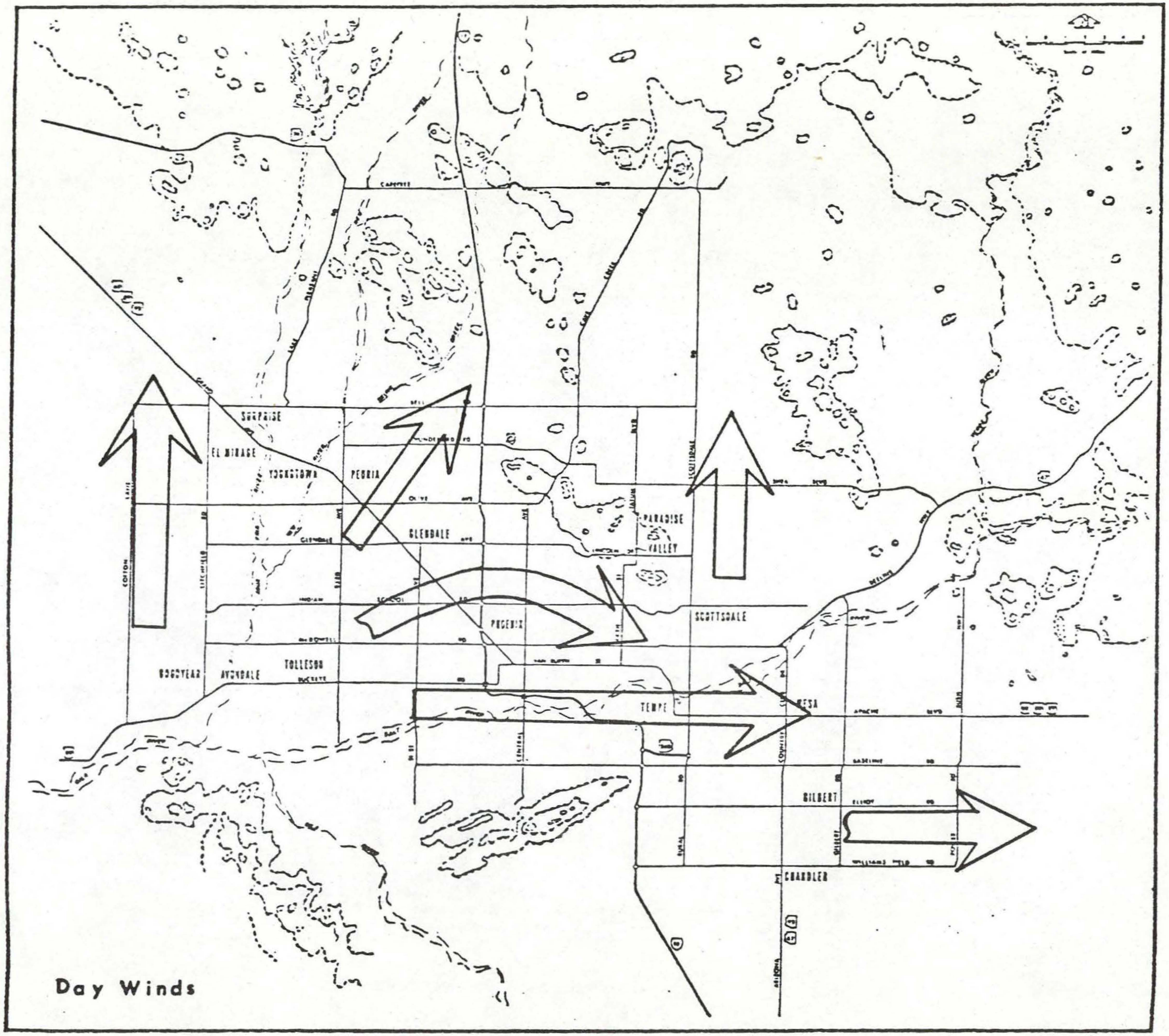


Figure 7. Upslope winds in the Salt River Valley near Phoenix in winter. The curved arrow in the center becomes straight and directed to the north in summer.

the discussion in the previous section should be used. Mixing height presentations, however, are reasonable. Only two upper air stations are presently operating in Arizona and these were used by Holzworth. In Arizona unless a front producing rain or winds with accompanying mixing is present, there is a strong ground based inversion from sunset to sunrise. After sunrise the solar heating leads to breakup of the inversion and finally to a very unstable atmosphere in the afternoon. For only about 10% of the time are fronts present. Therefore monthly average upper level data can be used to evaluate the mixing characteristics.

A set of typical observations of temperature vs. height for Tucson is shown on figure 8. Although this is for a single day, the averages are similar. An inversion is indicated when the temperature increases with height as on the early morning observation. On this particular day the height is 720 meters (which is very high for Tucson) before the temperature begins to decrease with altitude. At upper levels the temperature profile does not change much between early morning and afternoon. The "urban morning mixing height" is found by increasing the minimum surface temperature by one degree or so and drawing a line with a slope equal to the dry adiabatic lapse rate until the line intersects the measured curve shown. The height above the surface is called the mixing height. The afternoon mixing height is found in a similar manner using the maximum temperature at the surface and intersecting a dry adiabatic line with the afternoon radiosonde. Sometimes the morning radiosonde is used for both mixing heights. These mixing heights are not true representations of the heights to which pollutants will mix, but the afternoon one is qualitatively representative. The morning mixing height is best calculated from temperature measurements near the ground for extremely stable conditions and the urban heat island in Arizona can be

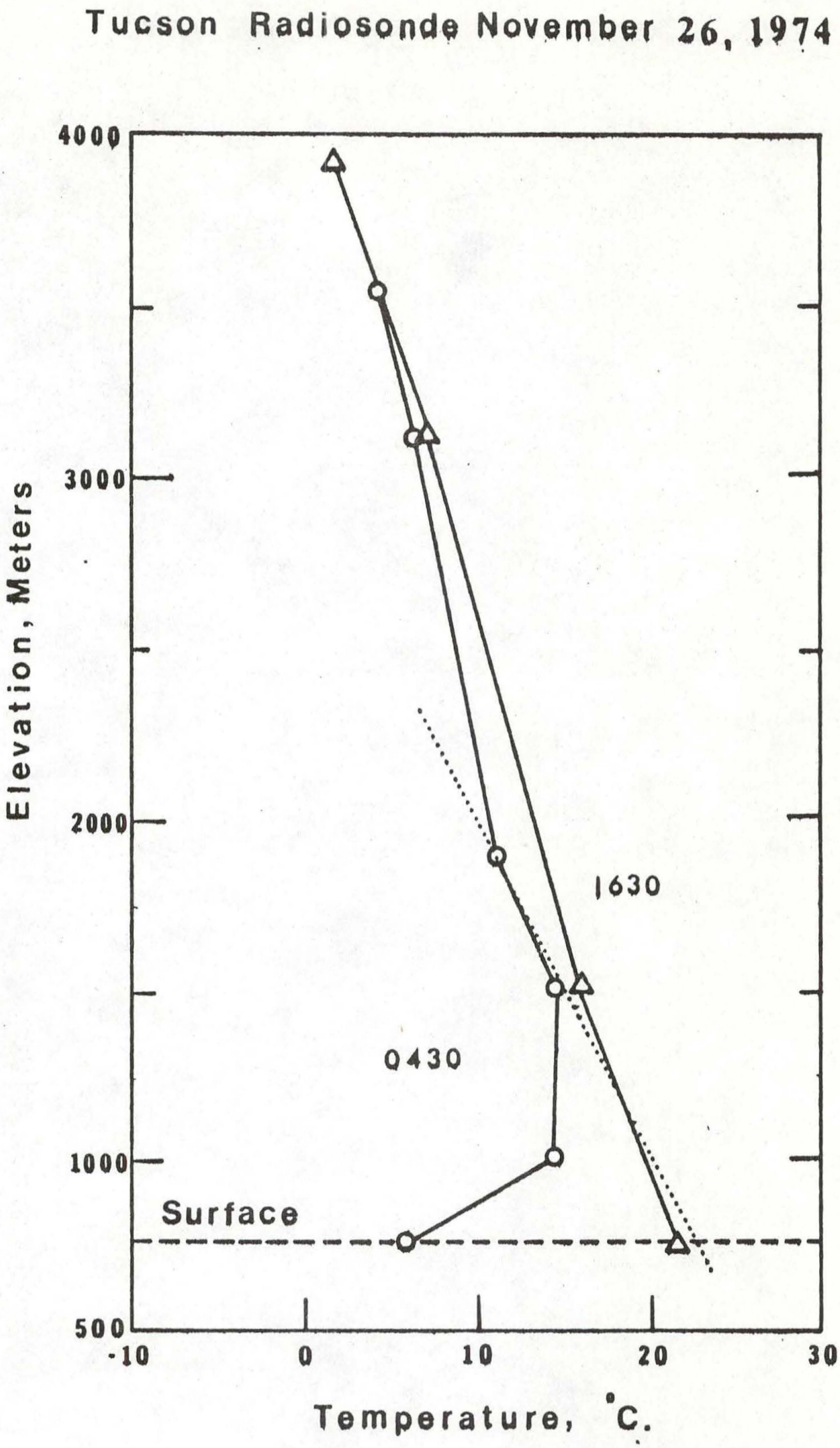


Figure 8. Tucson Radiosonde November 26, 1974 at 0430 and 1630 time.

ignored. Figure 9 shows the temperature difference between two heights at two locations in Phoenix. The extent and duration of strong stability, strong instability and abrupt changes between are shown. The diurnal cycle of vertical stability does not correspond to the wind shift cycle.

It is sufficient to use the temperature data of figure 9 to obtain the morning mixing characteristics along with a dispersion model. In the afternoon upper level mixing heights calculated as described would be more valuable than figure 9. Also the inversion depth in the morning can be used in stack design evaluation. This inversion depth is the same all year at four locations in Arizona and the average values are given below.

Location	Inversion Depth Meters
Phoenix	210
Tucson	223
Winslow	514
Yuma	407

There is a tendency toward shallower inversions during the spring and summer in the desert areas. The monthly variation of afternoon mixing height is shown on figure 10. Dry air and high solar heat flux in the spring months give the highest mixing heights.

There is a possibility that the afternoon mixing will be limited by an upper level inversion. Holzworth has tabulated the number of days of limited mixing at Tucson over a period of five years and at Winslow for three years. It is apparent from figure 10 that to avoid common winter values afternoon mixing heights of less than 500 meters only would be significant. During this period Tucson had only one period of two day's duration when the afternoon mixing height was less than 500 meters. The wind speed was between 4 and 6 meters per second during the two day period. Winslow in the three year span had 13 periods with mixing heights less than 500 meters and wind

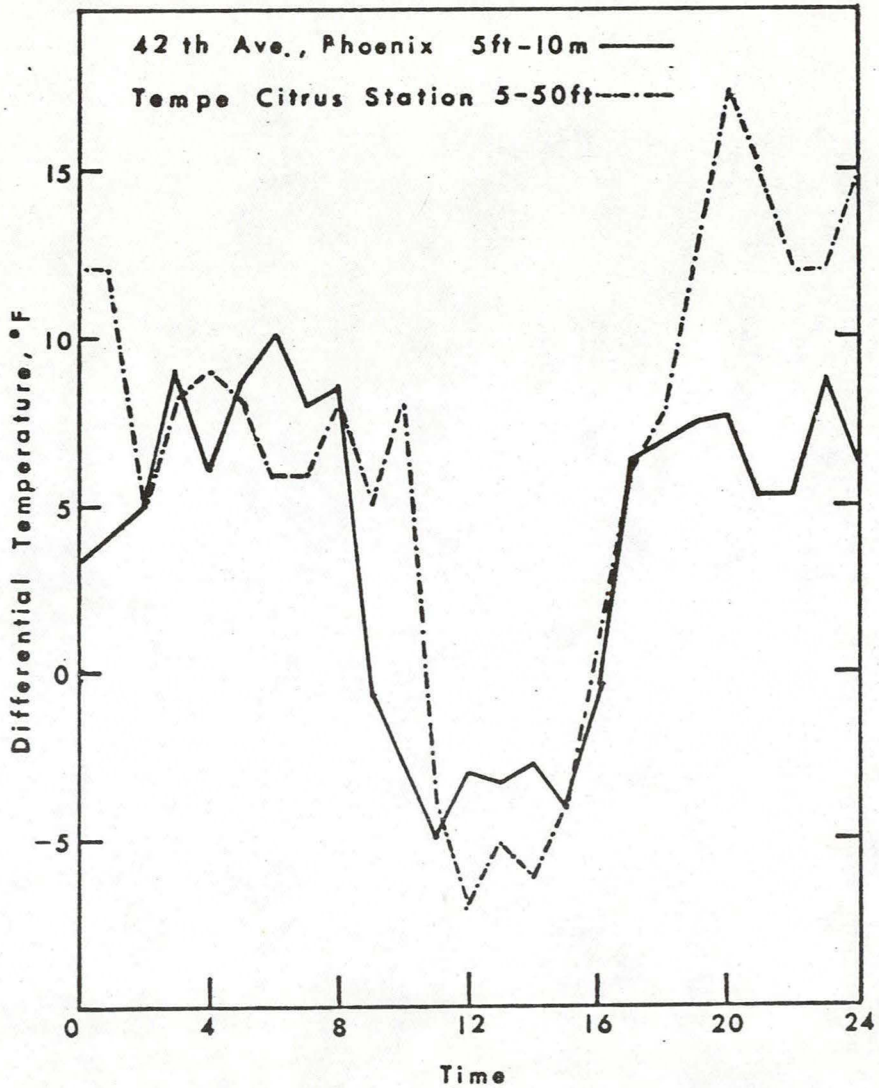


Figure 9. Diurnal Vertical Temperature differences at two locations near Phoenix, Arizona, November 26, 1974.

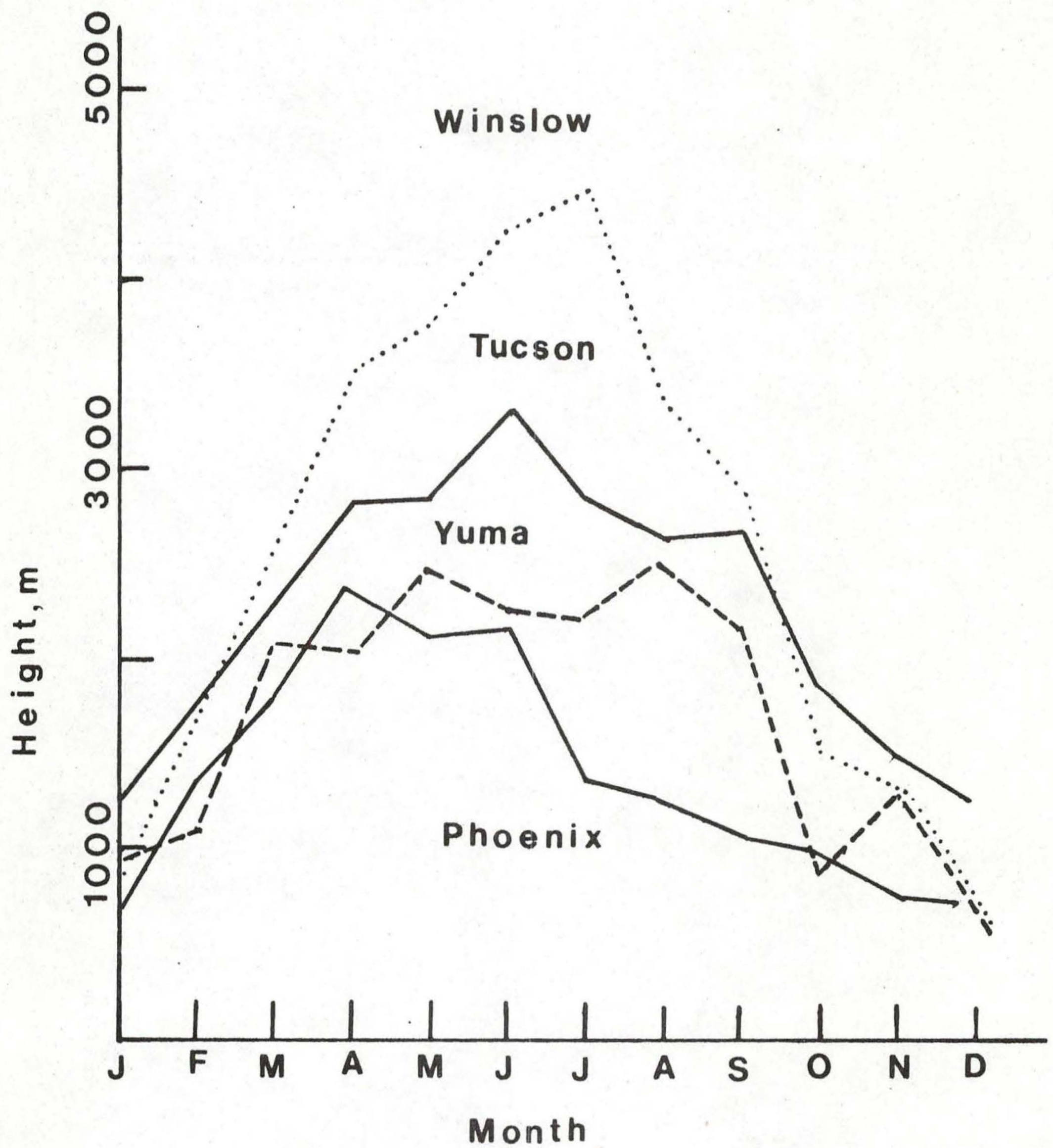


Figure 10. Afternoon mixing heights at four locations in Arizona. Yuma and Phoenix based on 2 years data; Winslow and Tucson, 5 years.
* See Appendix Table A-4 for data.

speeds less than 6 meters per second. Two periods were for greater than 5 days and a total of 49 days were involved. Las Vegas, Nevada, had 7 episodes for a total of 16 days with mixing heights less than 500 meters and wind speeds less than 6 meters per second. At both Las Vegas and Winslow most of the wind speeds were between 2 and 4 meters per second. The potential for prolonged episodes is thus greater in the northern and western parts of the state and is small in the south central area.

Prediction of Air Pollution Potential

One criteria in air pollution potential has just been discussed, the potential for prolonged episodes of low afternoon mixing heights and low wind speeds. Several episodes can be expected each winter in the northeast part of the state and perhaps one each winter in the southwest. The probability of an episode in the central and southeast parts of the state appears to be one in five or more years. In addition large point sources such as power plant stacks could be located above the top of the nighttime ground based inversion layer in the central and south central deserts since the inversion layer is less than 300 meters high. However, the deeper inversion layers in the west and north would prohibit this strategy. When emissions are released above the inversion layer, they will not mix to the ground until after the inversion breaks up. Release within the stable inversion layer also tends to limit mixing to the ground, but high concentrations can exist at the time of inversion breakup.

Inversion breakup is a condition which calls for estimation of pollution concentration on a short time average basis. Exact estimates of the average exposure at ground level at different distances from the point source are not possible at the present time. An idealized procedure called a Gaussian Plume Model can be used in this case and also for yearly averages

based on the wind frequency data for planning purposes. The justification for the model, illustrations of its use and tables of parameters corresponding to different atmospheric conditions can be found in Pasquill (1974), Slade (1968), Smith (1973) and Turner (1970) and other similar references. We will use the Gaussian model to compare air pollution potential at different locations in Arizona for a point source and an area source. Short term concentrations when influences of changing wind patterns, terrain, chemical reactions in the atmosphere and variations in emissions are important cannot be modeled as easily. We will discuss this problem and present some results for diurnal carbon monoxide concentrations in Phoenix, Arizona.

Gaussian Plume Models

Environmental Impact Statements for power plant or industrial construction use the Gaussian Plume Analysis as outlined by Smith or Turner to evaluate air pollution potential. This approximation for the vertical and cross-wind mixing leads to the equation

$$\frac{\chi}{Q} = \frac{1}{\pi\sigma_y\sigma_z\overline{U}} \exp\left(- \frac{y^2}{2\sigma_y{}^2} - \frac{H^2}{2\sigma_z{}^2}\right) , \tag{1}$$

Where χ is the concentration averaged over a time on the order of one hour, Q is the emission rate, $\overline{U}$, the average velocity of the wind, H, the height at which the emissions are released, σ, the standard deviations of plume concentration and y is the distance cross-wind. The standard deviations are functions of the distance from the source in the wind direction and the atmospheric stability. To obtain estimates of longer term averages, we first find the average crosswind (acw) χ/Q,

$$\left(\frac{\chi}{Q}\right)_{acw} = \int_{-\infty}^{\infty} \frac{\chi}{Q}\, dy = \sqrt{\frac{2}{\pi}}\, \exp\left(-H^2/2\sigma_z^2\right) \Big/ \sigma_z \overline{U}. \tag{2}$$

Then if wind frequency distributions are available for 16 different sectors or directions, the long term average (1ta) can be found by multiplying by the frequency and dividing by the width of the sector.

$$\left(\frac{\chi}{Q}\right)_{1ta} = \sqrt{\frac{2}{\pi}}\, f\exp\left(-H^2 \Big/ 2\sigma_z^2\right) \Big/ \sigma_z \overline{U}\,(2\pi r/16), \tag{3}$$

where r is the distance from the source in a direction corresponding to the wind frequency, f, and average velocity, $\overline{U}$. Many computer programs are available which use equation (3) to calculate concentrations for single or multiple sources in an area divided into a square grid. These include the Climatological Dispersion model (CDM) (Environmental Protection Agency 1973) and the Atmospheric Turbulence and Diffusion Laboratory (ATDL) model (Hanna, 1973). Both models include area sources as well as point sources but Hanna's program takes much less computer time. Hanna's computer program was used to calculate concentrations from a point source located at the center of a nine by nine grid with each grid square five kilometers on a side. The concentration, χ, is related to other variables in equation (3)

$$\chi = AfRQ/U,$$

where A is a constant, f is the wind direction frequency, R is a function of source height, distance from source and charcteristics of the atmospheric mixing, Q is the emissions rate, and U is the velocity. If we hold the function R and also Q constant, the ratio of f/U determines the concentration. Maximum concentrations for neutral stability corresponding to a yearly average

estimate are shown on figure 11. This representation of air pollution potential shows higher possible pollution exposures in the low wind speed areas of the state. The relative values shown on figure 11 would apply for a single point source at any height.

For yearly averages the neutral stability is commonly used leading to the relationship for σ_z,

$$\sigma_z = 0.15r^{0.75}. \tag{4}$$

The source square concentration is found by numerically integrating around all sectors and to the edge of the square. The maximum concentrations for a 100 meter high stack emitting 100 grams per second are shown on figure 11. These maxima always occur 3.3 kilometers from the source and in the direction that the winds blow to most frequently. Table A-5 in the appendix lists the direction. For a specific source at a specific height and a specific location a graph can be prepared as shown in figure 12a for Winslow. The southwestern prevailing wind leads to the location of maximum concentration to the northeast of the source. We have constructed such graphs for many locations in the state so that they can be overlaid on U. S. Geological Survey maps. Figure 12b shows the Winslow area portion of the USGS map. Appendix II contains a set of maps of isopleths with the locations for use as overlays. All the calculations are based on wind roses with frequencies in 16 directions and <u>one</u> average velocity. The wind measurements were taken at standard ground level heights for meteorological measurements.

We also have several sets of joint frequency distribution wind roses giving frequencies for the 16 directions for several average wind speeds (for example 1, 3, 5, and 7 meters per second). The results for

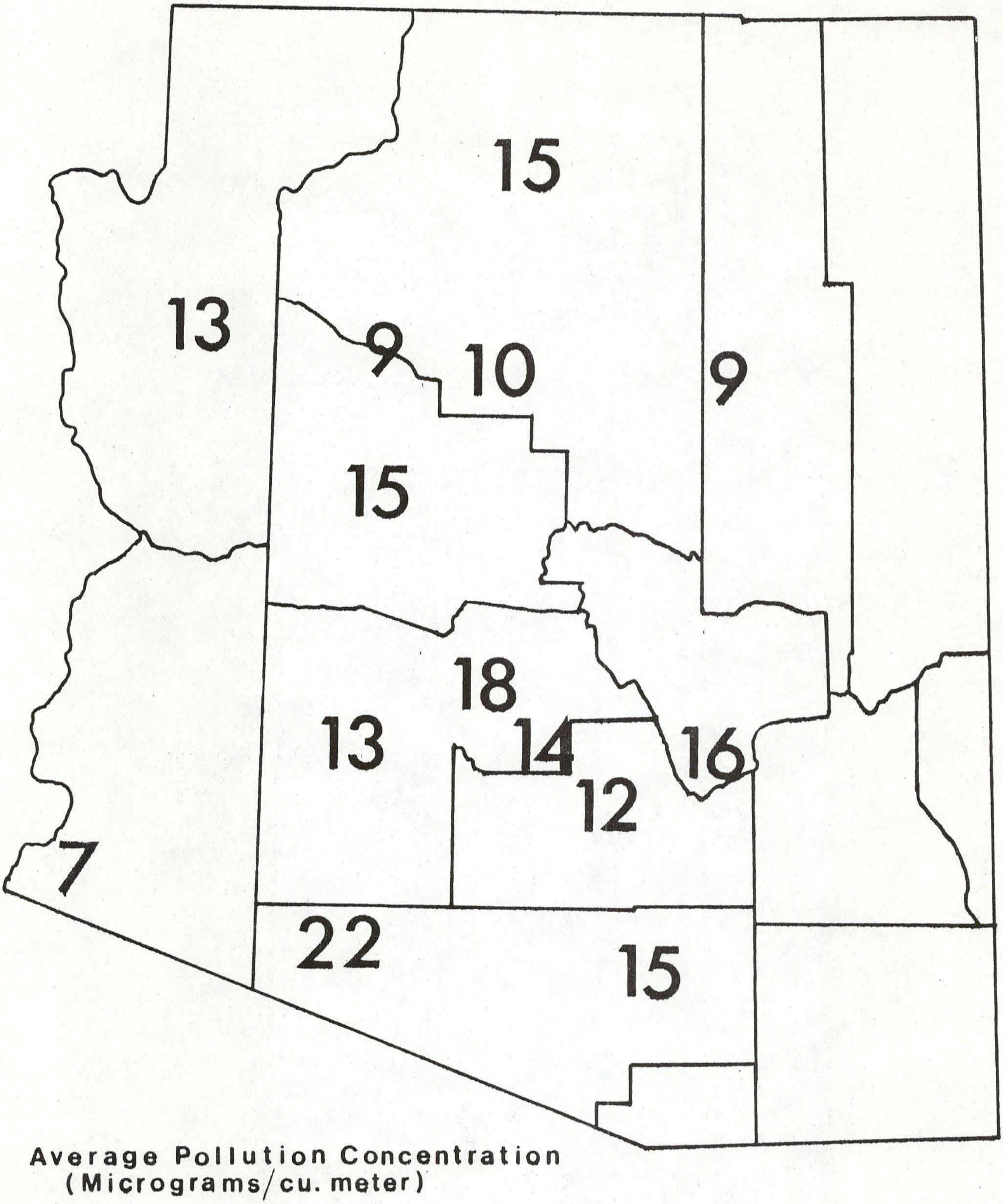


Figure 11. Maximum annual average pollution concentration due to a 100 meter stack emitting 100 grams per second, units are micrograms per cubic meter.
* See Appendix Table A-5 for data.

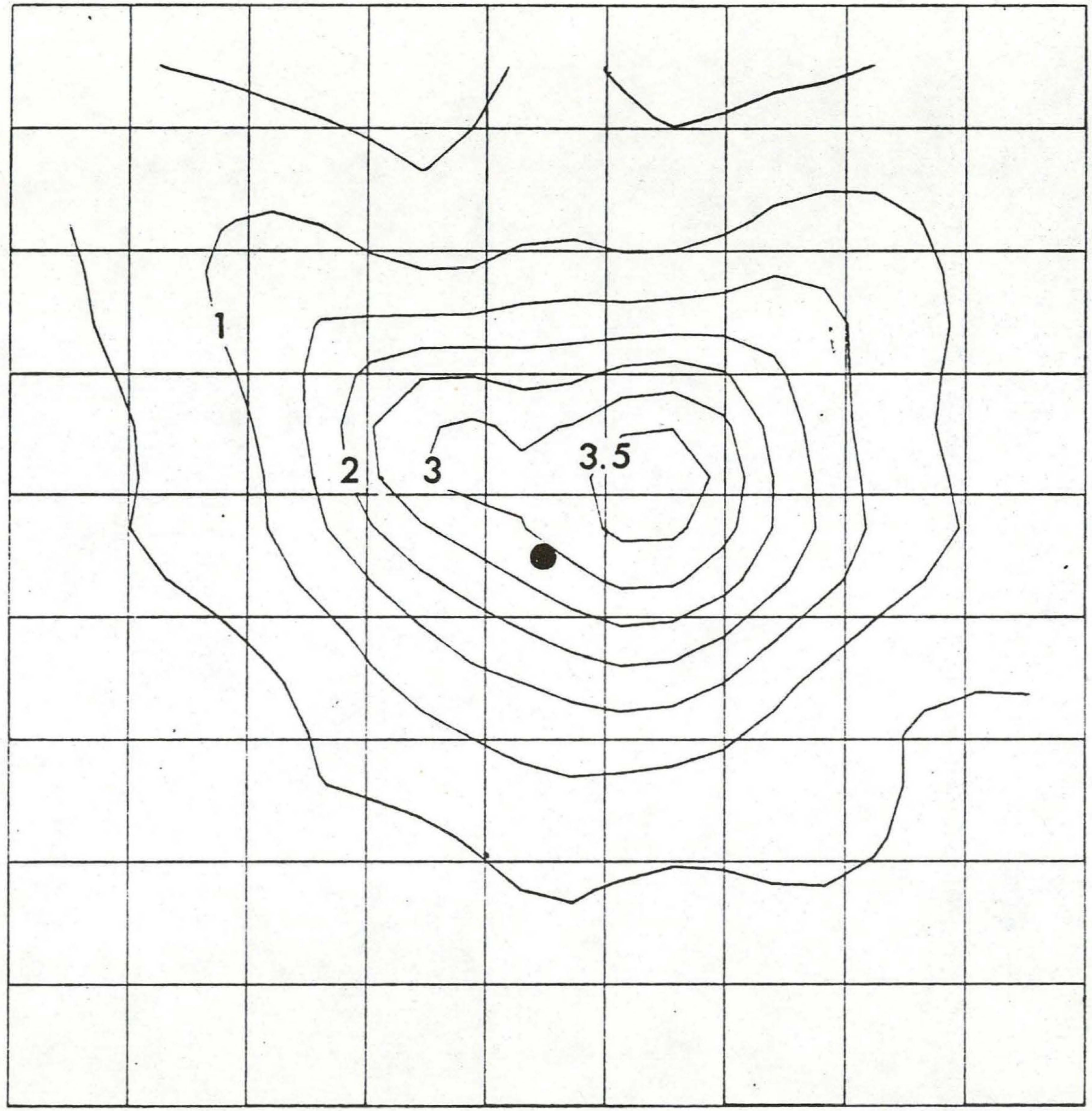


Figure 12a. Isopleths of concentration for a point source at Winslow, Arizona. The source is at the center dot. North is at the top. The maximum concentration within the 3.5 μg/m^3 isopleth is 9. Each square is 5 kilometers on a side.

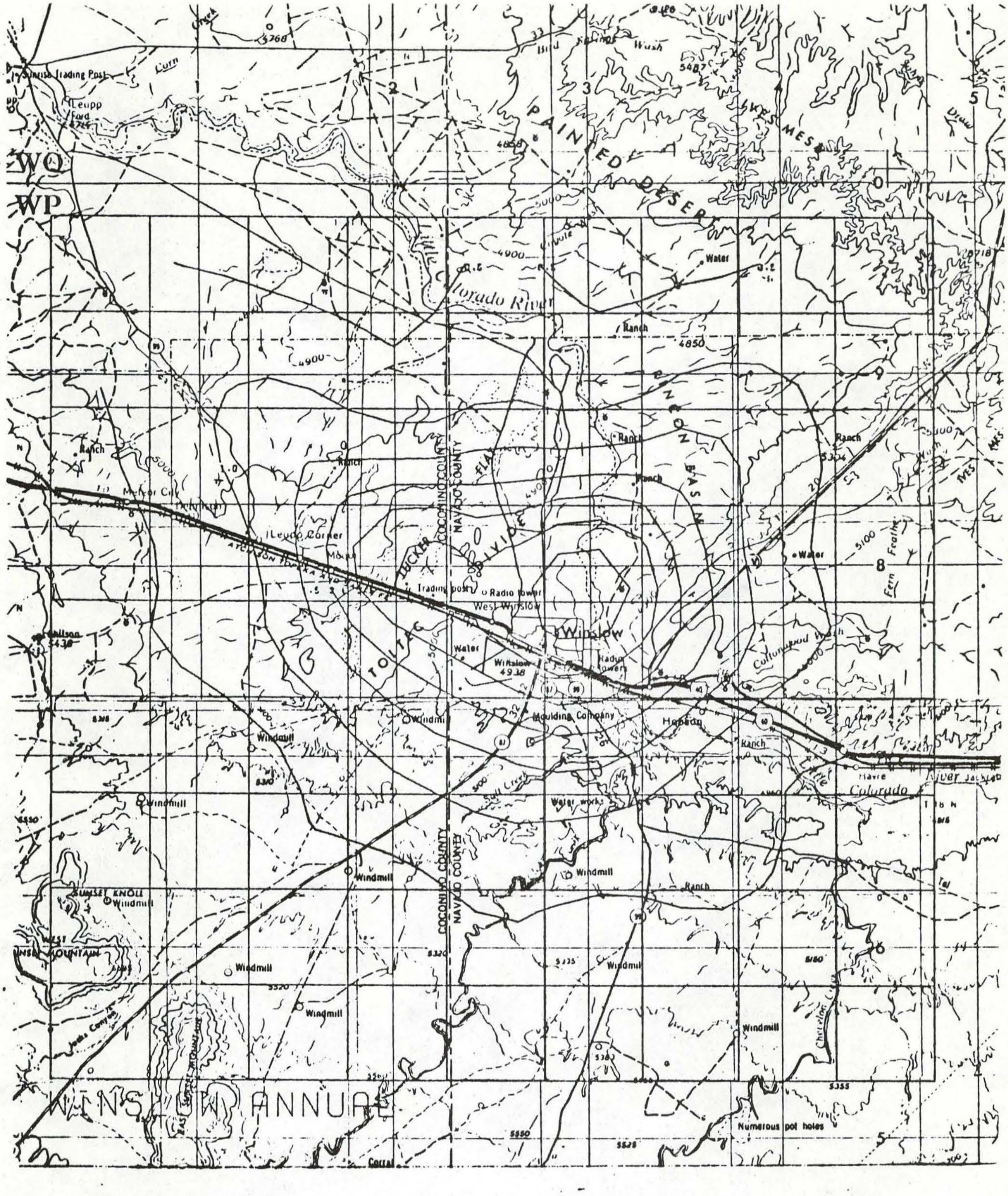


Figure 12b. Overlay of Figure 12a on USGS map of Winslow area.

maximum concentrations are similar when accurate wind instruments are used but are weighted by the calms recorded when low sensitivity instruments are used. We conclude that it is better to use just one average velocity when airport or historical data on winds are available. When a lower stack height is present, maximum concentrations occur nearer the source and are higher than for the 100 meter height. For example a 10 meter high stack gives 223 times the concentration at a distance of 154 meters from the source.

The highest local concentrations on an hourly average basis occur during inversion breakup. The maximum concentration is

$$\chi = Q \;/\; \sqrt{2\pi}\ \sigma_y\ \overline{U}\ L, \tag{5}$$

where L is related to the inversion or effective mixing height. The source occurs at the point σ_z is 0.47L. Examples of calculations for inversion break-up can be found in chapter 5 of Turner. In general the concentrations will be 100 times higher than the yearly average for the point sources at the location of maximum ground level concentrations. For such calculations the wind is assumed to blow in the same direction for the entire time and the breakup is accompanied by unstable mixing conditions. Actual inversion breakup occurs with variable winds, but maximum pollution concentrations would occur at the time of breakup. Since early morning inversions are present over 90% of the time in all parts of the state, this problem exists equally throughout Arizona. At Winslow the drainage winds blow from the southeast giving a second high concentration region northwest of the source. Since similar wind frequencies occur over most of the mountain and plateau of northern and eastern Arizona, the Winslow overlay can be useful for air quality potential evaluation over a wide area, at

least for yearly average concentrations. When impingement on a hillside is important, a detailed analysis of the wind frequency and stability in the proper direction is necessary.

The same computer program will also evaluate the average concentration for an area source. Automobiles, small industries and home burning and heating all combine to give a widely spread ground level emission. For comparison purposes we used emissions in a one kilometer square to obtain the ratio of concentration per unit area to emissions rate, χ/Q for the same locations as the point sources. The results are shown on figure 13 for the emissions square. On this yearly average basis neighboring squares had negligible concentrations. The numbers on figure 13 correspond to 30 to 50 second homes in the one kilometer square area if the units were micrograms per cubic meter and the contaminant carbon monoxide. In metropolitan Phoenix the levels would be a factor of 50 higher for the yearly average. Estimates were obtained from typical vehicle counts in Maricopa county.

Area sources are much more important on a short term basis, especially when ground based inversions are present. Such a condition is common at evening rush hours in urban areas, but may also relate to recreational areas when evening traffic is concentrated. A detailed model is discussed below. We can form an estimate of the magnitude of the problem by assuming that the emissions are well mixed in a box. If no winds are present and the height of the box is 12 meters, 3000 vehicles per hour moving within or through a box one kilometer square will give a carbon monoxide concentration of 10 ppm. Persistence of this concentration over an eight hour period would exceed present federal and state standards. The large urban areas of Arizona have emissions as much as four times the above example. The traffic volume would be characteristic of a developing

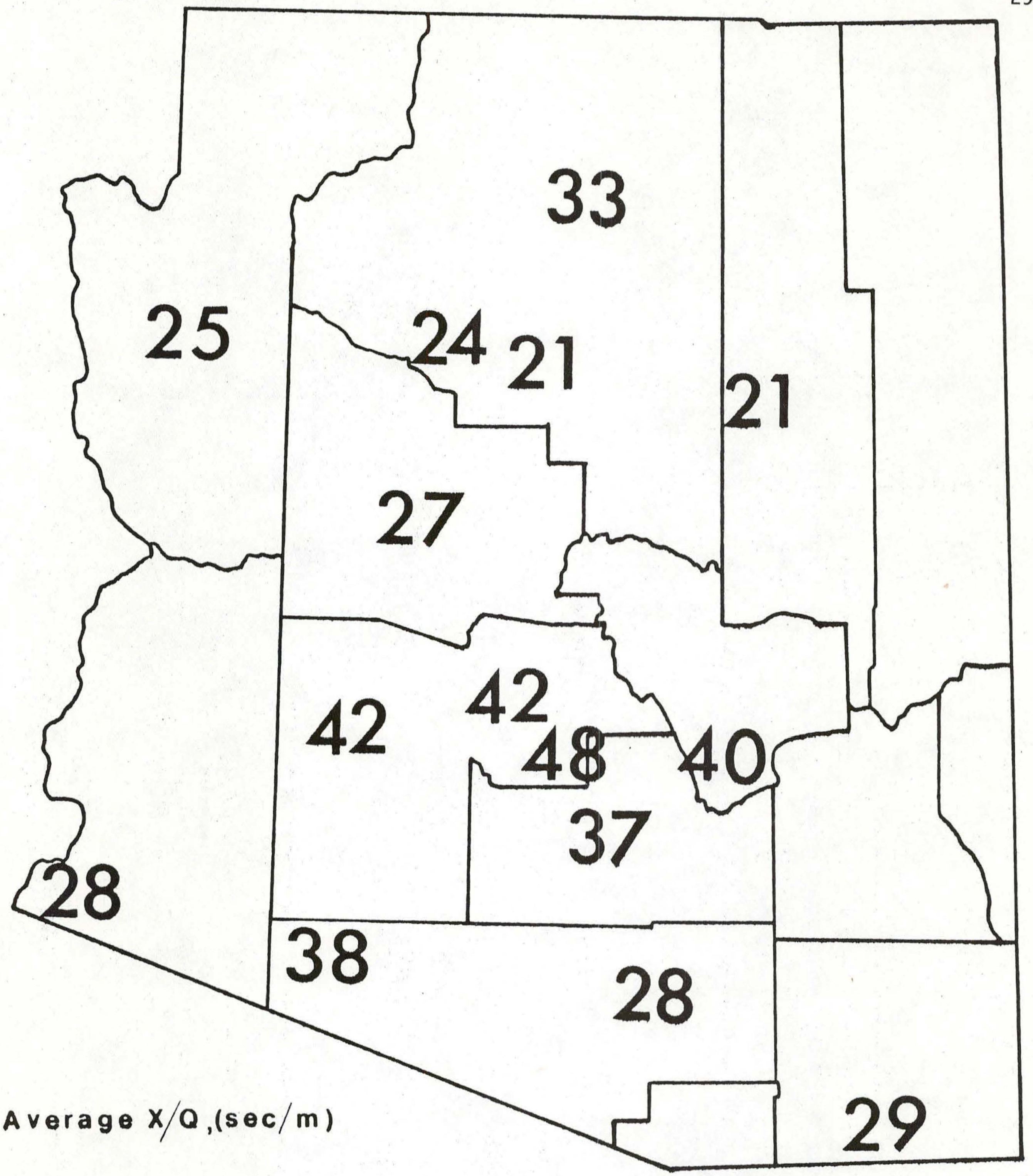


Figure 13. Annual average urban χ/Q, seconds per meter. Relative values shown for a one kilometer square emissions area.
* See Appendix Table A-5 for data.

surburban area of Phoenix but could represent a local concentration of second home developments.

Airshed Modeling

To adequately treat the area source problem more than one mixing box must be considered in a complete airshed model. Many of the aspects of urban airshed modeling are discussed by Seinfeld, Reynolds and Roth (1972). Here we want to look at some results and the application to pollution potential. A complete study includes solving the equations of motion, energy and mass transport for the airshed in question. In general this is not possible at present so the wind field and energy effects must be known. For simulation of a current day or series of days, the emissions amounts and locations are forecast and used also as known quantities. Then modeling programs solve for concentrations throughout the airshed numerically. These programs use some approximation for the turbulent vertical mixing usually related to atmospheric experiments.

When terrain effects on the wind field are pronounced, some form of airshed modeling is necessary for urban areas. The success of this type of modeling is dependent on extensive knowledge of the local wind field. Information on Phoenix was gathered by Berman and DeLaney (1975) and used in "box model" to show the distribution of carbon monoxide in the Phoenix area during a typical winter day when no fronts influenced the weather. A box model uses a lid on the valley with pollutants well mixed below the lid. The lid height can be varied with time to account for changes in mixing from the stable (limited mixing) inversion at night to the unstable mid afternoon. Carbon monoxide is produced almost entirely by automobiles so the emissions vary during the period of the simulation also.

The mixing height has been used in the single box analysis already.

For the Phoenix model if we assume the mixing height is equal to σ_z, an appropriate expression from Slade (1968) is

$$\sigma_z^2 = a[1-\exp(-k^2t^2)] + bt \tag{6}$$

where a, b, and k are functions of the degree of stability and the equation is for stable atmospheres at the Hanford site. Using the values for a, b and k and an average time of 450 seconds, σ_z is 6 meters for very stable conditions and 15 meters for moderately stable conditions. A similar analysis for the unstable afternoon condition gives a σ_z in excess of 50 meters. Evaluations at other times give an increase with time of 40% for stable, 75% for near neutral and 200% for unstable conditions over one hour.

Measurements of temperature difference at two heights were shown on figure 9. Very stable conditions are present from midnight until 8 a.m. and again after 4 p.m. Conditions are unstable from 10 a.m. until 3 p.m. A shadow is suspected to be responsible for the late change at the citrus station in the morning.

The mixing height was assumed to reach a maximum at 2 p.m. and a smooth curve drawn from 7 a.m. to this maximum for the Phoenix model. Decay is assumed to occur abruptly after 4 p.m. up to a point. That is it takes some time for a vertical turbulence generated in the afternoon to decay. To compute the dacay time we can use the following analysis.

$$\frac{1}{2}\frac{du^2}{dt} \sim -\frac{u^3}{\ell}$$

where ℓ is a length scale and u a velocity scale for the turbulent mixing. Integrating

$$\frac{1}{u} - \frac{1}{u_o} = \frac{t}{\ell}$$

We can neglect u_0, the velocity scale for the unstable afternoon and use

$$u = 0.1 \text{ m/sec}$$

$$\ell = 1800 \text{ m}$$

where ℓ is the mixing height attained after 180 minutes starting with 50 meters and expanding by a factor of 1.35 every 15 minutes. Then

$$t = 5 \text{ hours} \quad .$$

The length scale of 1800 m also corresponds to a vertical velocity of 3 meters per second which can be obtained from the input solar radiation. If 10 percent of the incoming 300 watts per square meter at 3 p.m. is converted to turbulence, the result is a 3 meters per second turbulent velocity. Then a turn around time of 10 minutes gives the length scale. Thus the mixing height should decay for 5 hours from 4 p.m. to 9 p.m. before reaching a minimum. The minimum appears to be more stable at 9 p.m. than the morning minimum so the lowest mixing height was assumed at that time.

The computer program utilized a convection analysis for the horizontal transport with the wind. Results are computer maps as shown on figures 14 to 16. Some pockets of high pollution potential can be pinpointed on these maps and in Phoenix show up in the summaries of monitoring sites. We found that the weakly developed upslope winds were an important factor leading to high concentrations of carbon monoxide and these winds were much less important on the measured wind direction distribution. The weak upslope winds were unable to push the pollutants generated in the central part of Phoenix over the low mountain barriers to the north, so the concentration would build up after sunset when limited vertical mixing

Figure 14.

Phoenix, Arizona   Carbon Monoxide Concentrations Calculated for 11-26-74

20 ppm and over   10-19 ppm   2-9 ppm limits

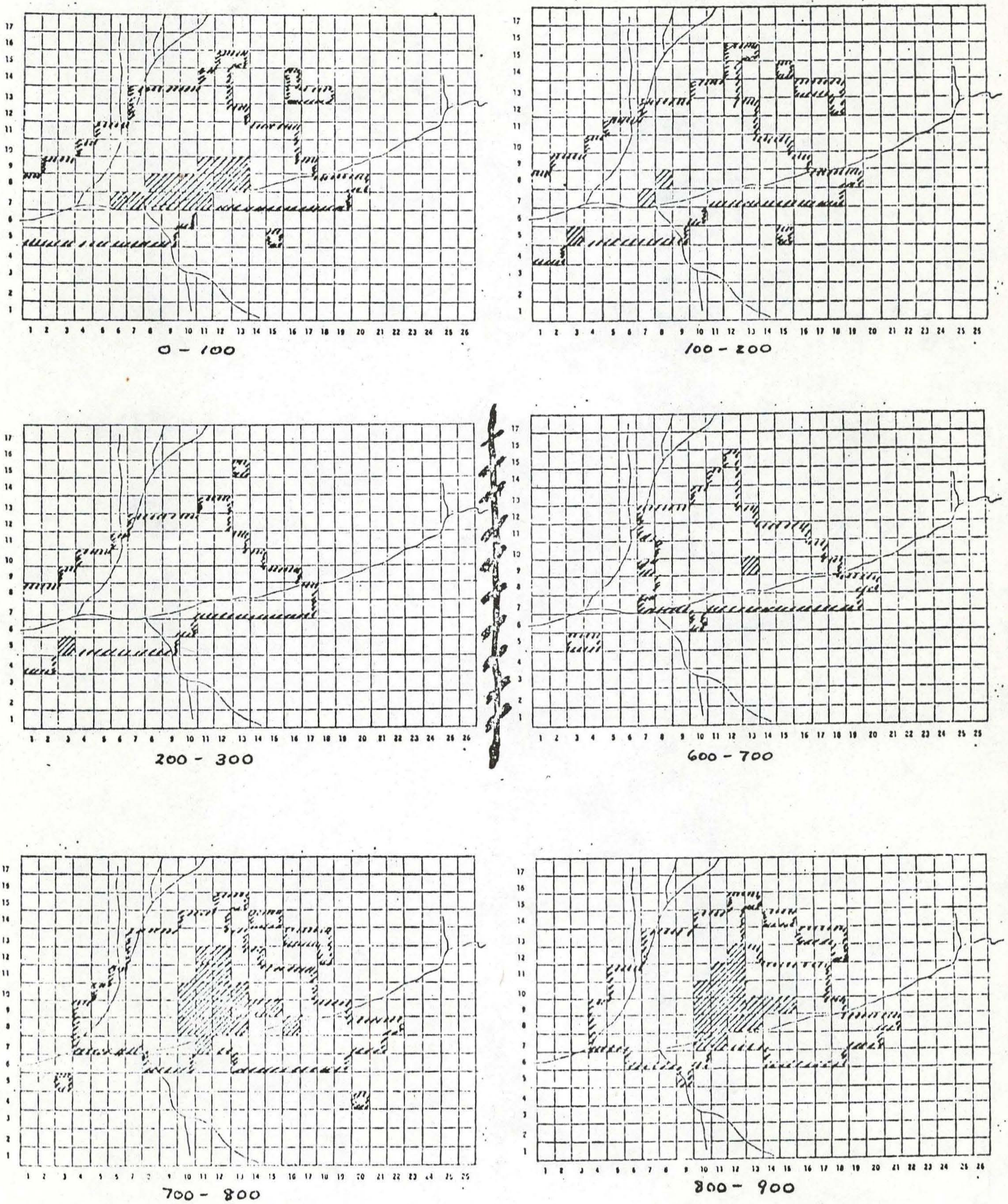
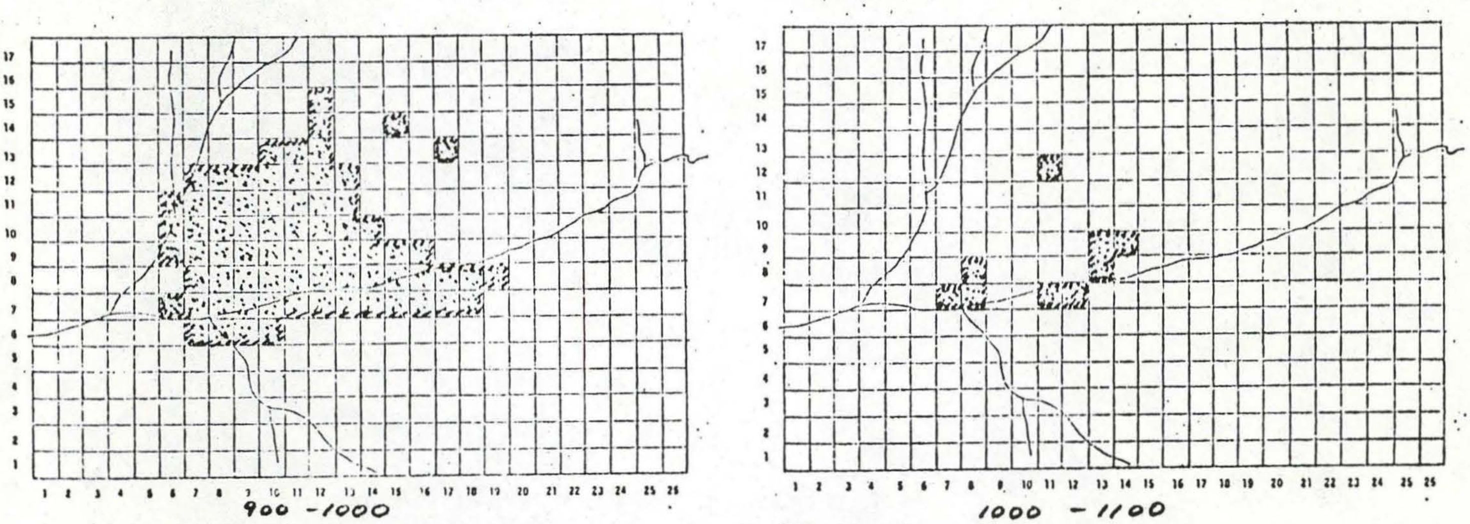


Figure 15.

Phoenix, Arizona Carbon Monoxide Concentrations Calculated for 11-26-74

10-19 ppm 2-9 ppm limits



[concentrations between 1100 and 1600 are less than 2 ppm throughout the entire grid]

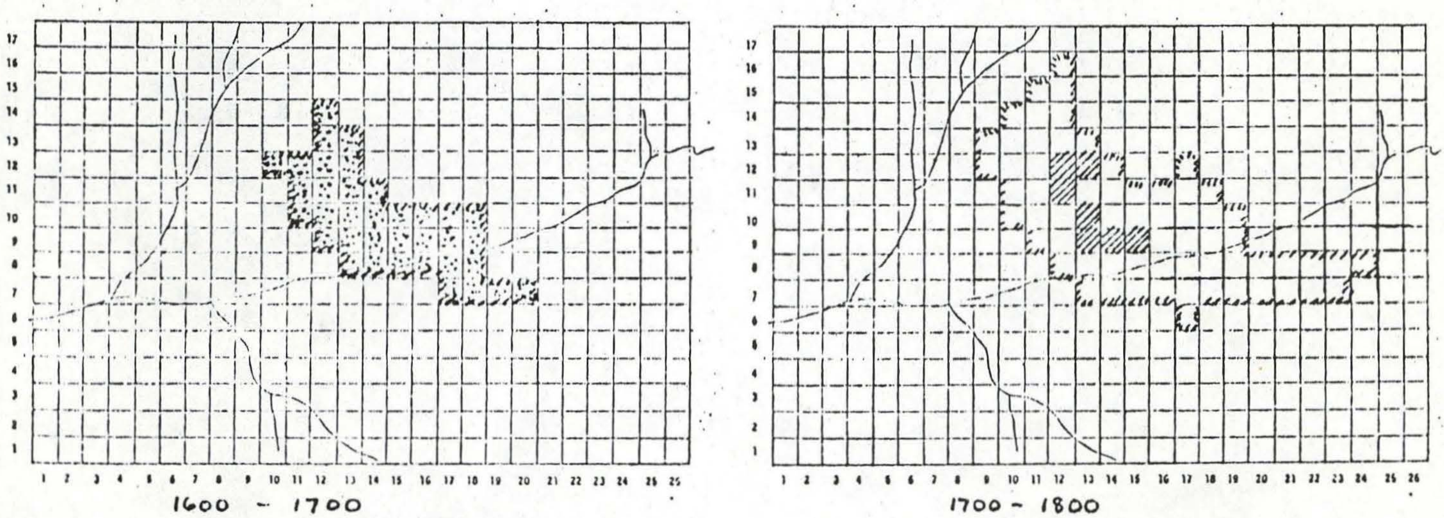
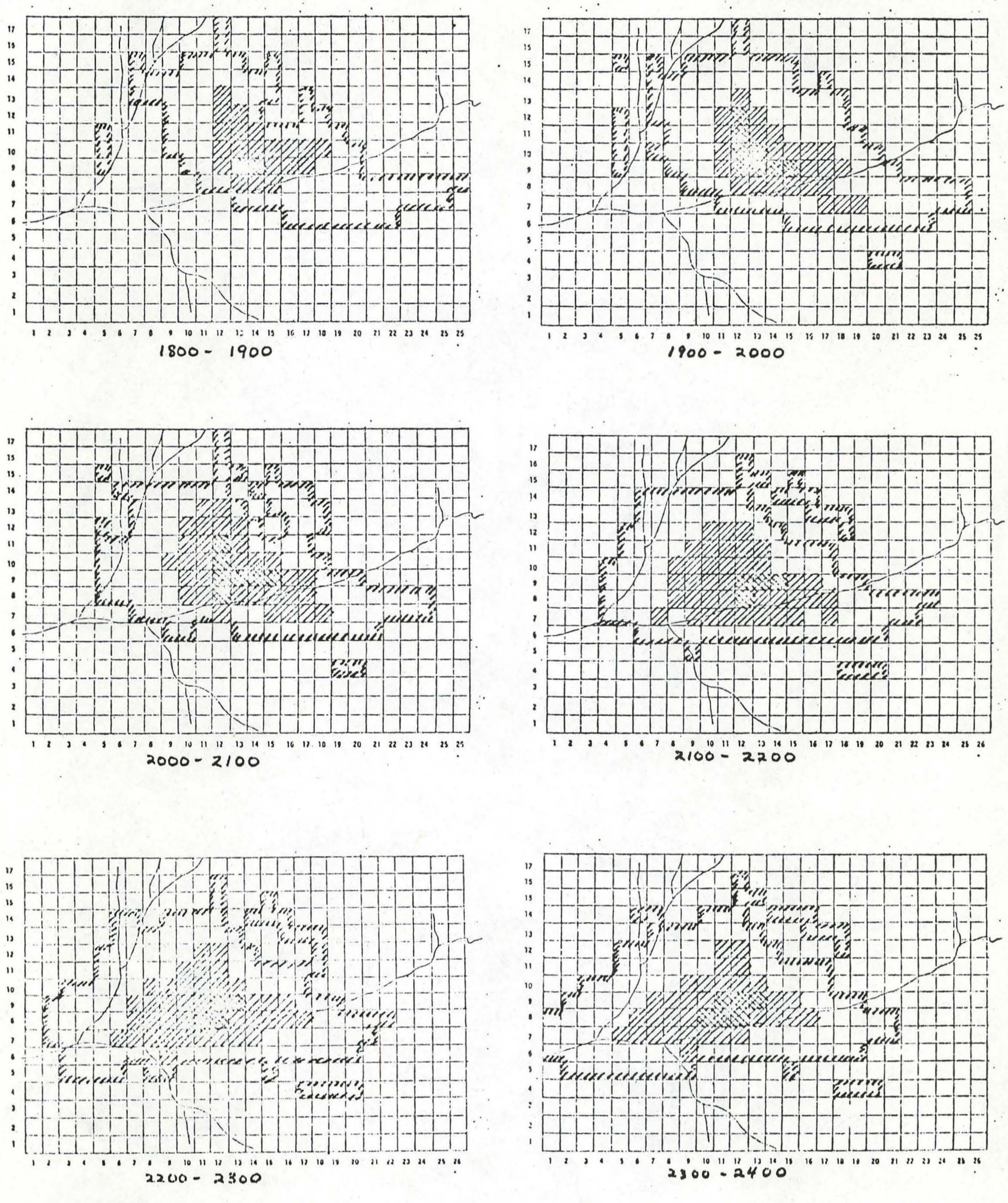


Figure 16.

Phoenix, Arizona Carbon Monoxide Concentrations calculated for 11-26-74

20 ppm and over 10-19 ppm 2-9 ppm limits



began. Figure 16 shows the concentrations near their peak level and figure 14 shows the cloud moving out of the valley along the drainage winds in the morning. Comparison of the computer model with measurements near downtown Phoenix are shown in figure 17. Such airshed studies can be used for rural areas and the cost for simple models is comparable to that for the Gaussian Plume Analysis.

The detailed analysis can also be used to show the importance of transport and production mechanisms at any location within the grid. Figure 18 shows the results for the maximum emission location in Phoenix. When the night wind is dominant, most of the carbon monoxide found at this location comes from up wind areas. During the afternoon and evening when the day wind is present, most is produced within the area itself and remains. Note that the switch occurs precisely at the time of wind reversal, approximately 8 p.m.

When pollutants must be tracked on an hour to hour basis, airshed modeling can give excellent results. Although we have discussed one particular day, this day represents one of the worst in Phoenix in the 1974-75 winter. The wind height variations with time are representative of days with potentially high carbon monoxide levels at times in the future. If we feed projected automobile emissions for the future into the model, the airshed technique can be used to predict air pollution potential and aid in planning.

Similar pollution problems can be expected to occur throughout Arizona. A local analysis perhaps combined with the estimation of airflow patterns (Fosberg et al. 1975) could be applied to areas of unknown wind flows.

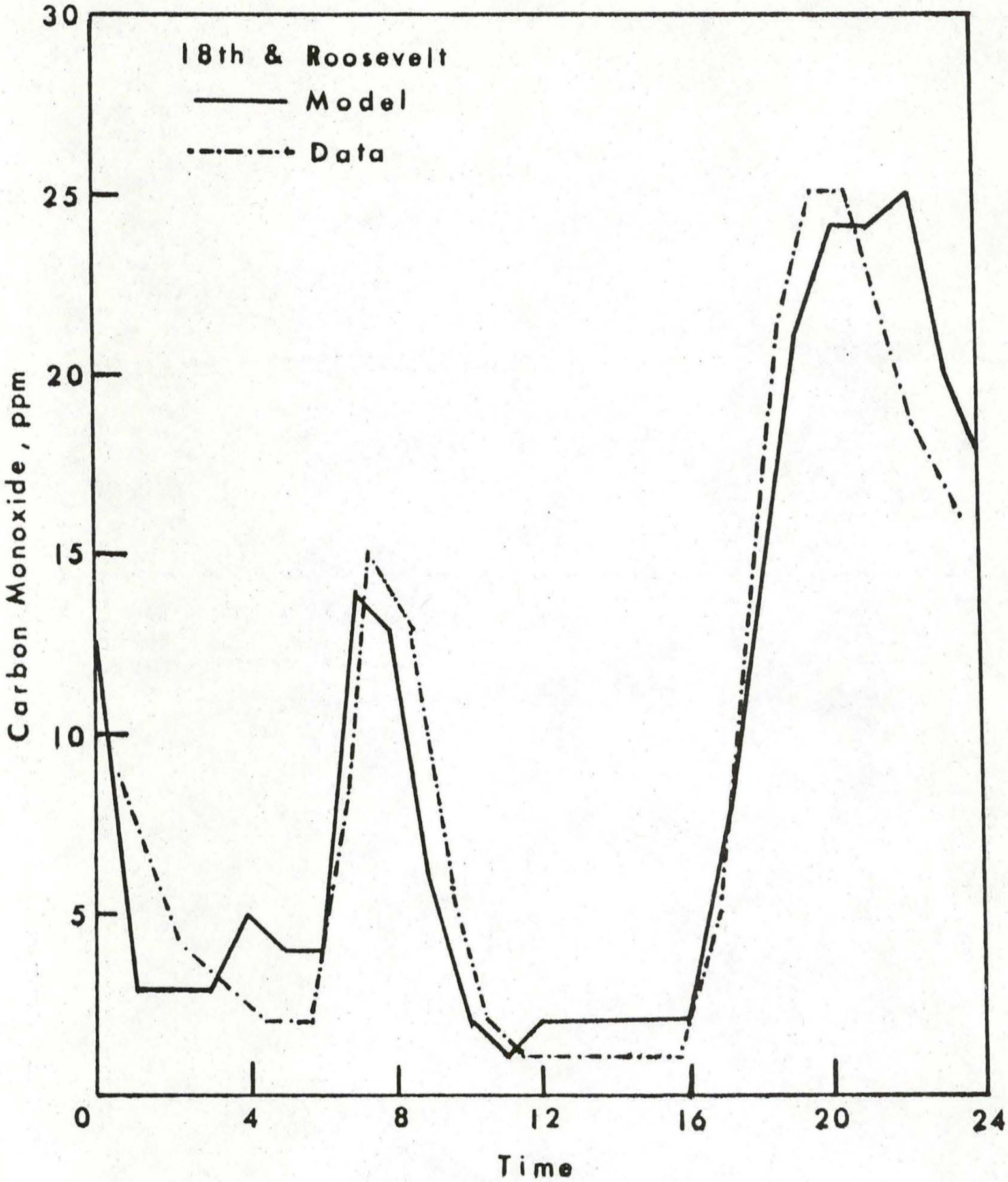


Figure 17. Comparison of computer model carbon monoxide concentration with measured data at 18th and Roosevelt location in Phoenix, Arizona.

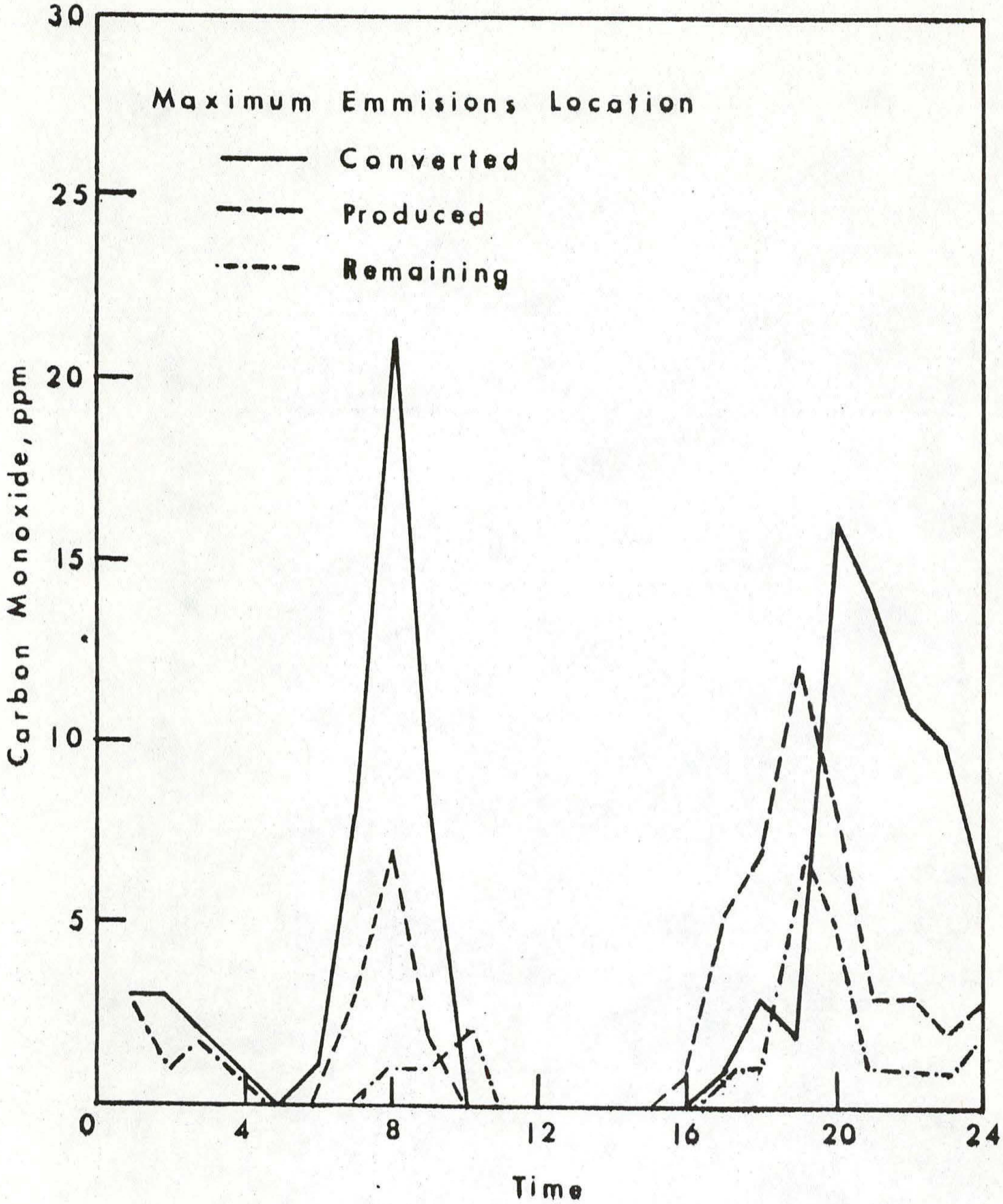


Figure 18. Transport Mechanisms in the grid square responsible for the maximum emissions from automobiles in Phoenix. (November 26, 1974 simulation)

CONCLUSION

In this report summaries of current and potential air pollution in Arizona have been presented. This work represents a considerable improvement over previously available wind speed and mixing height tabulations for the evaluation of sites in the state for industrial and housing development. The abrupt change in wind direction north to south across the entire state and early morning inversion depth east to west across the southern half of the state need more clarification. Studies are needed in the Mogollon Rim area, between Phoenix and Yuma and in the south east part of the state to provide improved maps which can be used to estimate air pollution potential.

ACKNOWLEDGEMENTS

This work was supported in part by a grant from the Eisenhower Consortium for Western Environmental Forestry Research and the University Grants Committee of Arizona State University. Assistance from the Maricopa County Health Department, the Arizona State Health Department, the Maricopa Association of Governments, the Salt River Project and Arizona Public Service Company is gratefully acknowledged.

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APPENDIX I

Appendix I consists of five tables giving the city locations for data shown on the maps of the text.

Table A-1

Particulate Data for Figure 1

Reference: State of Arizona Health Department

Location	Annual Geometric Mean TSP, µg/m^3 1973
Ajo	103
Apache Junction	33
Buckeye	176
Bullhead City	32
Douglas	90
Flagstaff	73
Florence	107
GM Proving Grounds	72
Grand Canyon	22
Green Valley	57
Hayden	185
Holbrook	32
Mescal	50
Montezuma Castle N M	28
Morenci	56
Organ Pipe N M	34
Page	27
Petrified Forest	26
Phoenix	144
Tucson	78
Winslow	58
Yuma	110

Table A-2

Sulfur Dioxide Data Figure 4

Reference: State of Arizona Health Department

Location	Annual Average Concentration $\mu g/m^3$ 1973
Ajo	34 (Mining Town)
Buckeye	2
Clifton	90
Coolidge	9
Davis Dam	2
Douglas	Mining Town
Florence	25
Globe	Mining
Grand Canyon	6
Green Valley	3
Hayden	Mining
Holbrook	5
Mammoth	15
Mescal	11
Miami	Mining
Morenci	Mining
Oracle Junction	30
Page	2.6
Phoenix	9
San Manuel	Mining
Tucson	7
Vail	6
Winkleman	Mining

Table A-3

Wind Data for Figure 5

Reference: State of Arizona

Location	Winds		
	Average Speed, mph	% Frequency SW sectors	% Frequency, direction next high
Aho	5.9	15	33 - SE
Ash Fork	9.5	26	16 - N
Coolidge	6.1	20	19 - E
Douglas	7.7	21 (N)	23 - SE
Globe	5.6	31	24.- SE
Grand Canyon	6.9	30	22 - S
Kingman	9.0	37	13 - SE
Palo Verde Nuclear	5.4	23	-
Park	10.6	28	15 - E
Phoenix	5.4	16	32 - E
Prescott	8.5	43	-
Saguaro (N of Tucson)	2.7	22	38 - SE
Tucson	8.1	18	39 - SE
Winslow	10.7	34	21 - SE
Yuma	8.1	21	23 - N

Table A-4

Early Morning Inversion Depths and Afternoon Mixing Depths

(Data for Figure 10)*

Month	Tucson		Phoenix		Yuma		Winslow	
	Morning	Afternoon	M	A	M	A	M	A
J	230	1250	290	620	430	920	500	800
F	230	1750	290	1340	420	1040	500	1680
M	220	2260	210	1750	430	2060	500	2530
A	210	2810	170	2370	400	2030	790	3480
M	210	2830	175	2100	380	2430	500	3770
J	210	3330	170	2160	370	2250	510	4250
J	230	2830	175	1370	400	2210	550	4450
A	220	2610	175	1310	380	2500	550	3380
S	220	2630	180	1010	380	2180	530	2850
O	220	1870	200	980	400	860	510	1570
N	240	1490	240	750	440	1260	520	1370
D	240	1220	250	710	440	620	490	720

* The information for this table was obtained from the monthly average radiosondes given in Climatological Data, National Summary, U. S. Department of Commerce, NOAA.

Table A-5
Maximum Air Pollution
Data for Figures 11 and 13

Location	Pt Source $\mu g/m^3$	Concentration Direction	Area Source χ/Q
Ajo	22	NNW	38
Ash Fork	9	S	24
Chandler	14	NW	48
Coolidge	12	W	37
Douglas	8	NW	29
Gila Bend	13	NNW	42
Globe	16	ESE	40
Grand Canyon	15	NE	33
Kingman	13	NE	25
Park	10	N	21
Phoenix	18	W	48
Prescott	15	NE	27
Tucson	15	NW	28
Winslow	9	NE	21
Yuma	7	S	28

APPENDIX II

Appendix II contains an explanation of the computer program used to evaluate yearly average concentrations from a point source. Maps for 15 locations in Arizona are also given separately and as overlays on USGS maps.

Illustrative results for Winslow, Arizona are presented first and then other maps follow. The computer printout for a 100 meter stack emitting 100 grams per second is given in table A-6 for two grid sizes. The one kilometer grid was used to find the maximum concentration and the larger grid to prepare the computer maps.

The map is shown on figure A-1. A program available on the Arizona State University Univac 1110 was used to generate the maps. This program performed some averaging so the maximum contour is 3.5 micrograms per cubic meter while the peak is approximately 9. The ATDL model program as modified is presented in Appendix III. It includes the calculation of the maximum concentration and location mathematically. The scale used in figure A-1 is exactly the same as the 1: 250,000 USGS map. We have made Xerox transparencies and then placed these on the USGS map. The Winslow result is given in the text and the others are in this appendix.

When the geographical setting is similar, the location of the source can be moved to find estimates of air pollution potential 50 to 100 miles from the location indicated. This procedure is commonly followed in preparing environmental analyses for annual average exposures. The Winslow data has been used for Snowflake which is 50 miles away. Snowflake would be expected to have downslope winds from the south in addition to the "prevailing" west to southwest wind. St. Johns 50 miles east of Snowflake has a downslope wind from the east and the large scale pressure gradient winds are again from the southwest. Although minor variations in the frequency distribution are present, the Winslow winds can be used for all three locations for the maximum concentration estimates.

Table A-6

WINSLOW ANNUAL GRID DIMENSIONS 1 KM

CONCENTRATIONS FROM ELEVATED SOURCES WITH HEIGHT = 100.000

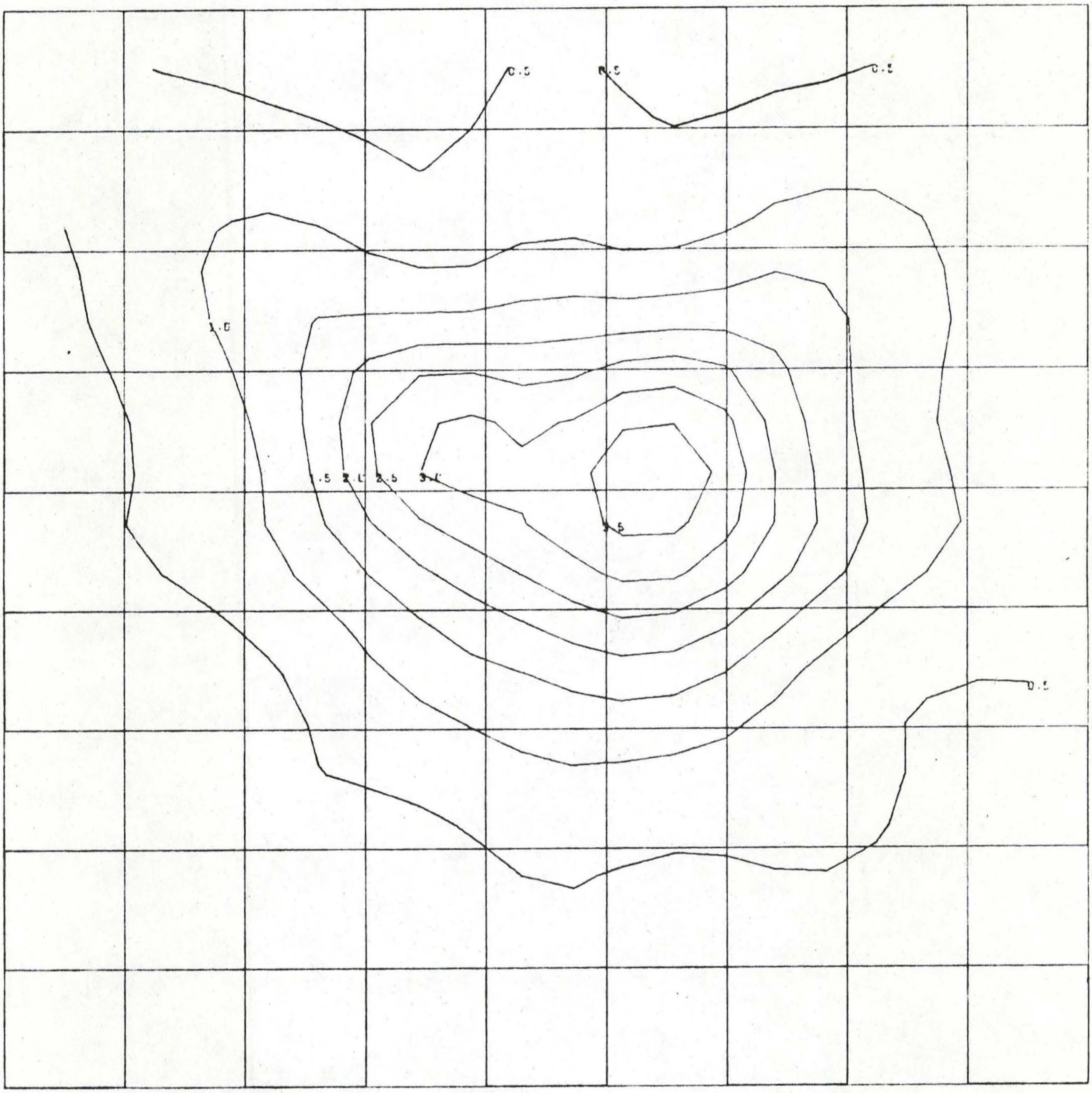
6.42	.00	2.29	.00	4.17	.00	2.29	.00	6.92
.00	7.97	.00	2.39	4.29	2.39	.00	8.60	.00
2.58	.00	8.18	1.82	2.81	1.82	8.83	.00	5.22
.00	2.69	2.05	1.77	.07	1.91	4.16	5.45	.00
3.23	3.32	2.18	.05	.00	.11	4.20	6.41	6.22
.00	.92	.70	.53	.04	.76	1.73	2.26	.00
.88	.00	2.47	.77	1.68	1.19	3.53	.00	2.17
.00	2.41	.00	1.01	2.57	1.56	.00	3.44	.00
1.94	.00	.97	.00	2.49	.00	1.49	.00	2.77

WINSLOW ANNUAL GRID DIMENSIONS 5 KM

CONCENTRATIONS FROM ELEVATED SOURCES WITH HEIGHT = 100.000

.62	.00	.30	.00	.55	.00	.30	.00	.67
.00	1.00	.00	.41	.88	.41	.00	1.08	.00
.34	.00	1.92	.77	1.61	.77	2.07	.00	.69
.00	.47	.87	5.05	2.53	5.45	1.76	.95	.00
.43	.68	1.25	1.94	3.23	3.94	2.41	1.31	.82
.00	.16	.29	1.52	1.43	2.18	.73	.39	.00
.11	.00	.58	.32	.96	.50	.82	.00	.29
.00	.30	.00	.17	.52	.27	.00	.43	.00
.18	.00	.13	.00	.33	.00	.20	.00	.26

Figure A-1



WINSLOW ANNUAL

List of Maps

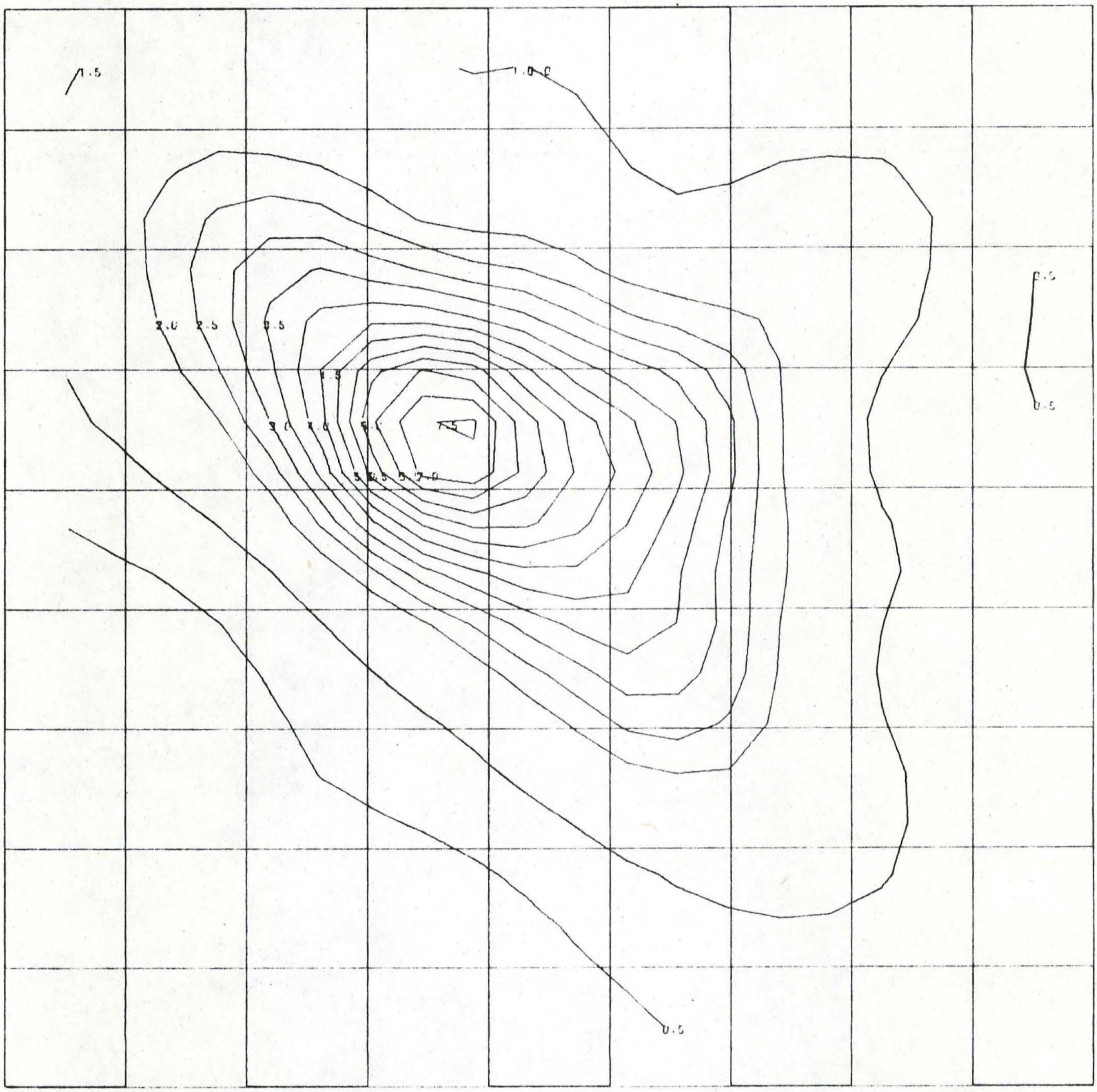
* Also in text.

Figure A-2a - 15a

Annual Average Ground Level Concentrations

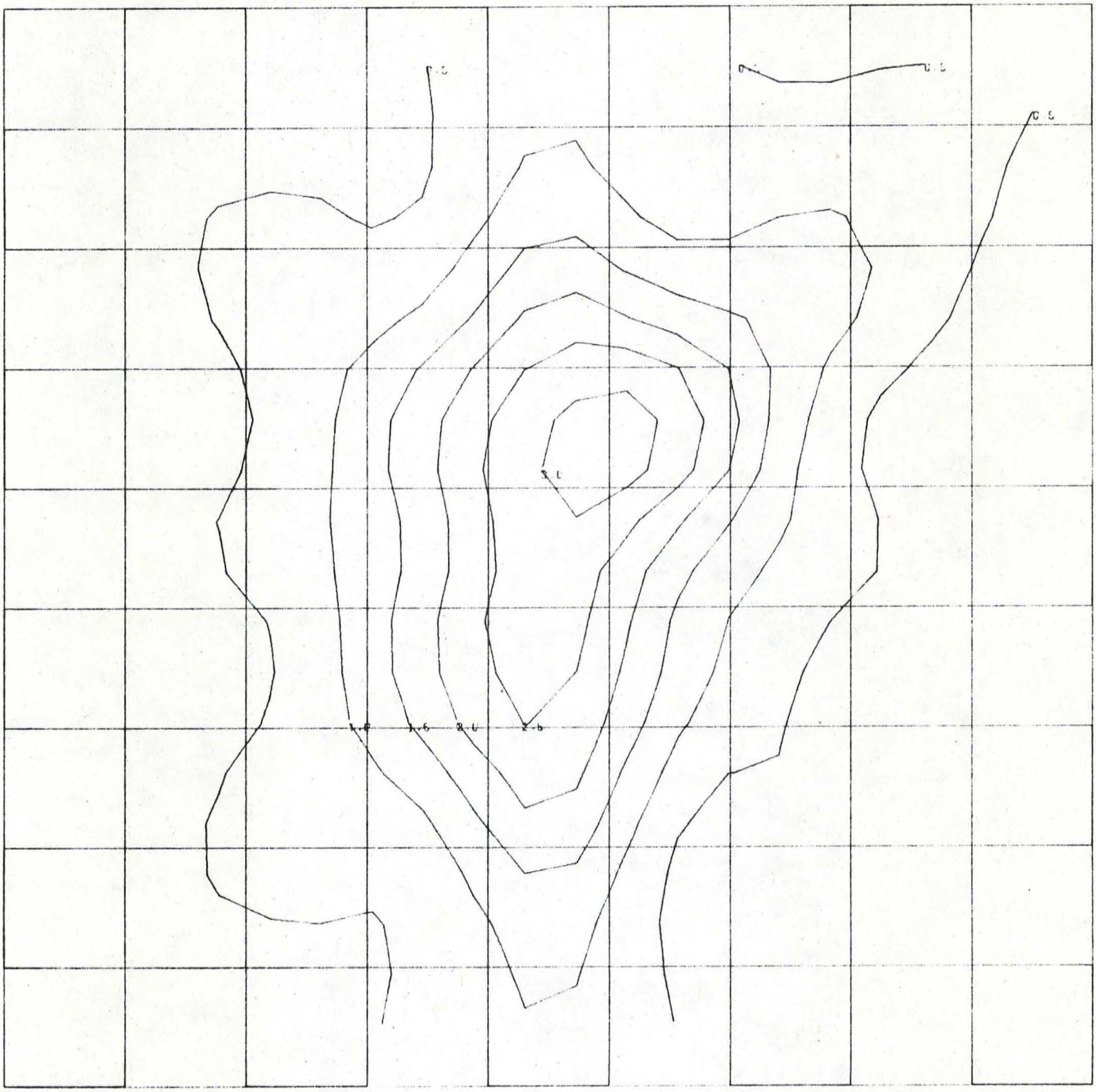
Source is at the center, 100 g 1 sec, 100 meter high, grid squares 5 kilometers on each side corresponds to 1:250,000 scale on USGS maps.

Figure A-2a



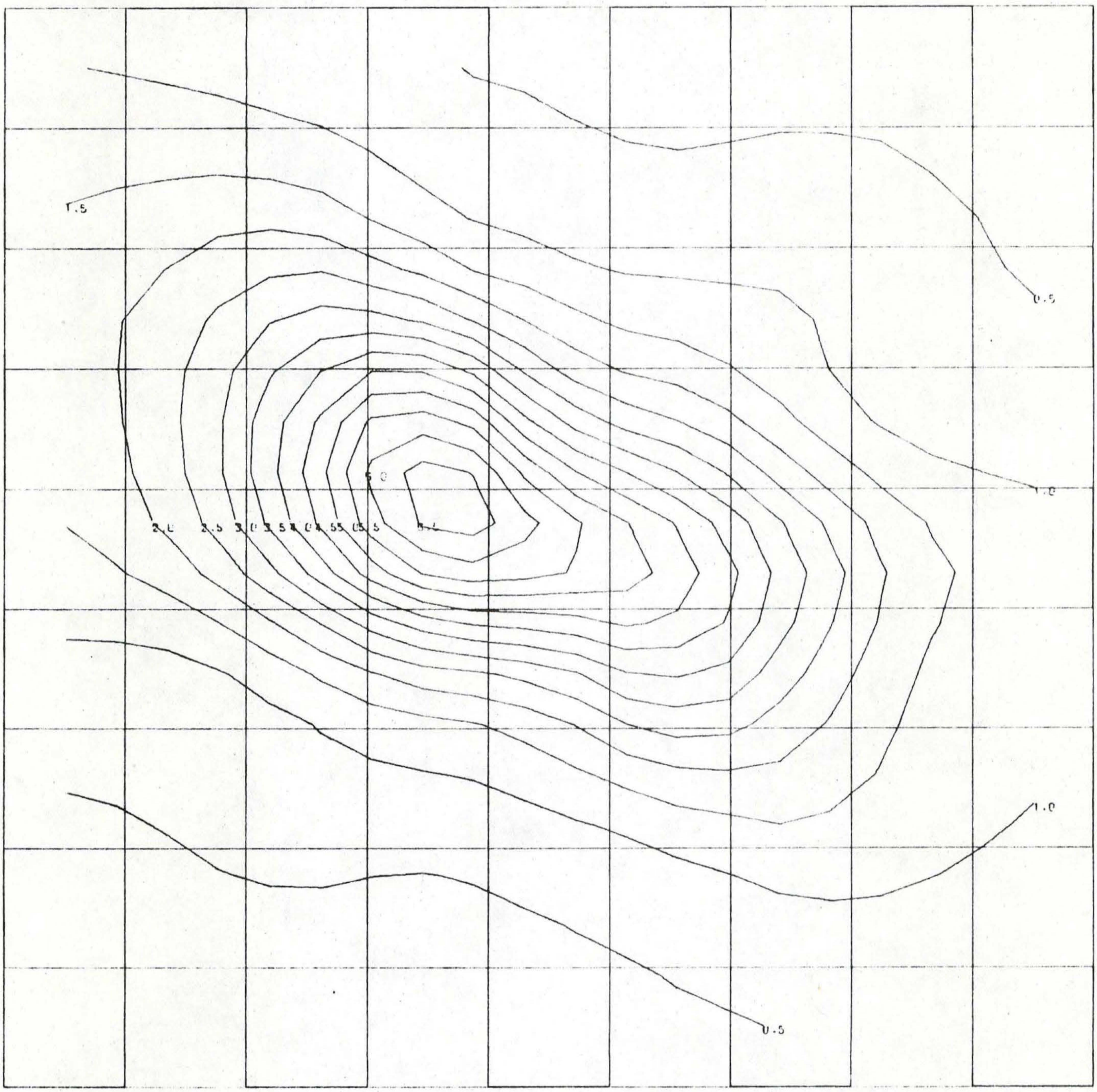
AJO ANNUAL

Figure A-3a



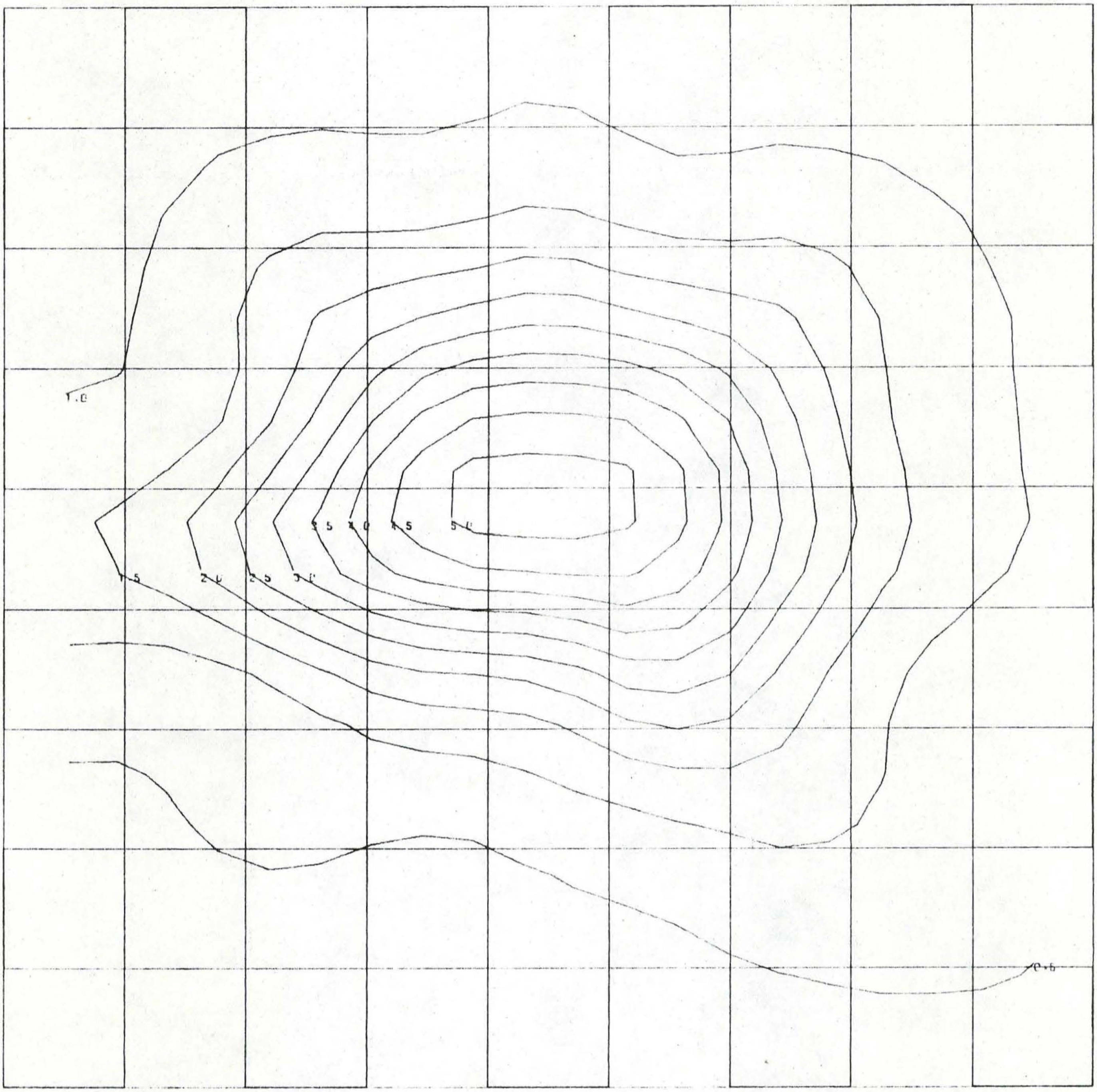
ASH FØRK ANNUAL

Figure 7.4i



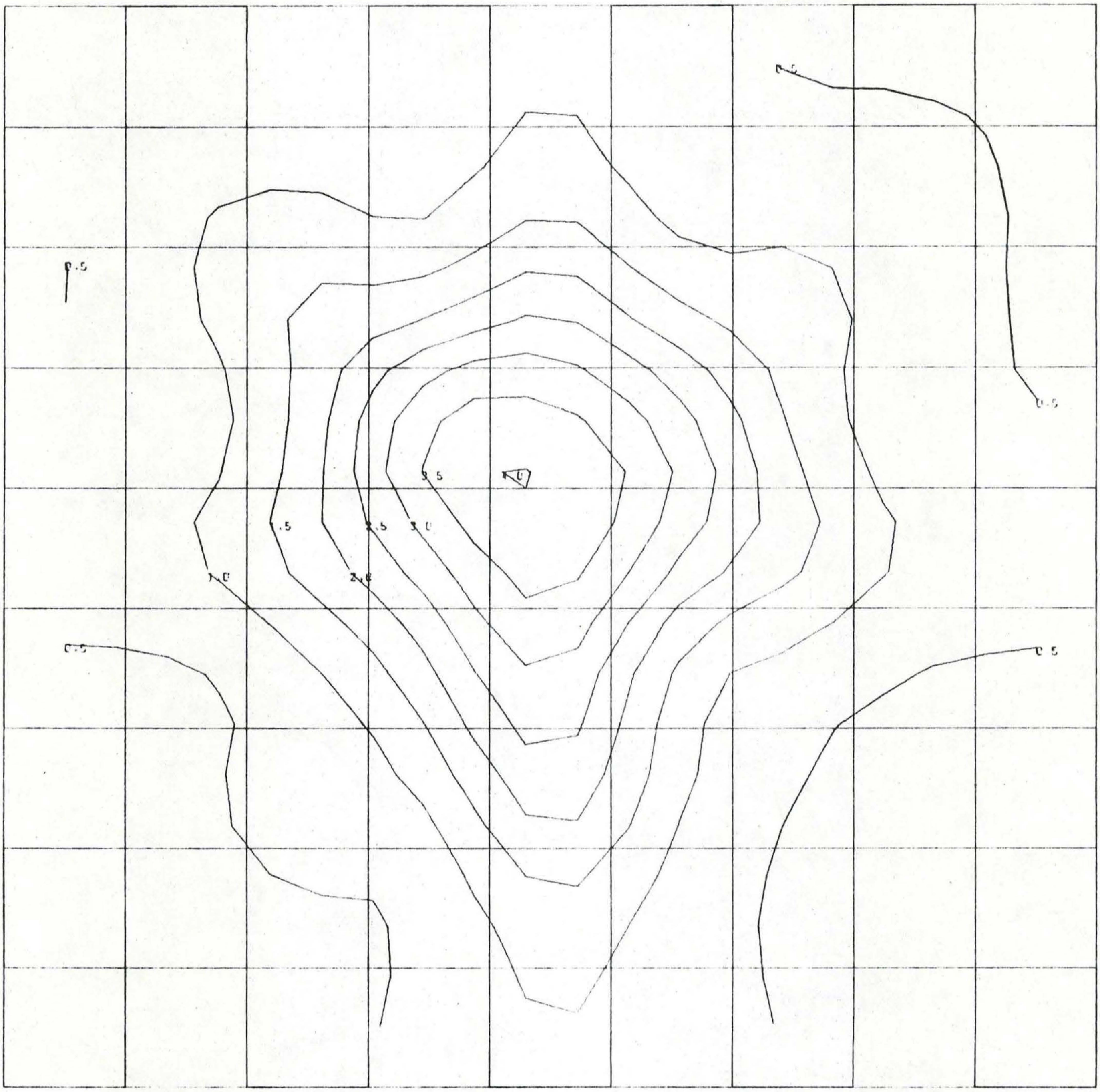
CHANDLER ANNUAL

Figure A-5a



COOLIDG ANNUAL

Figure A-6a

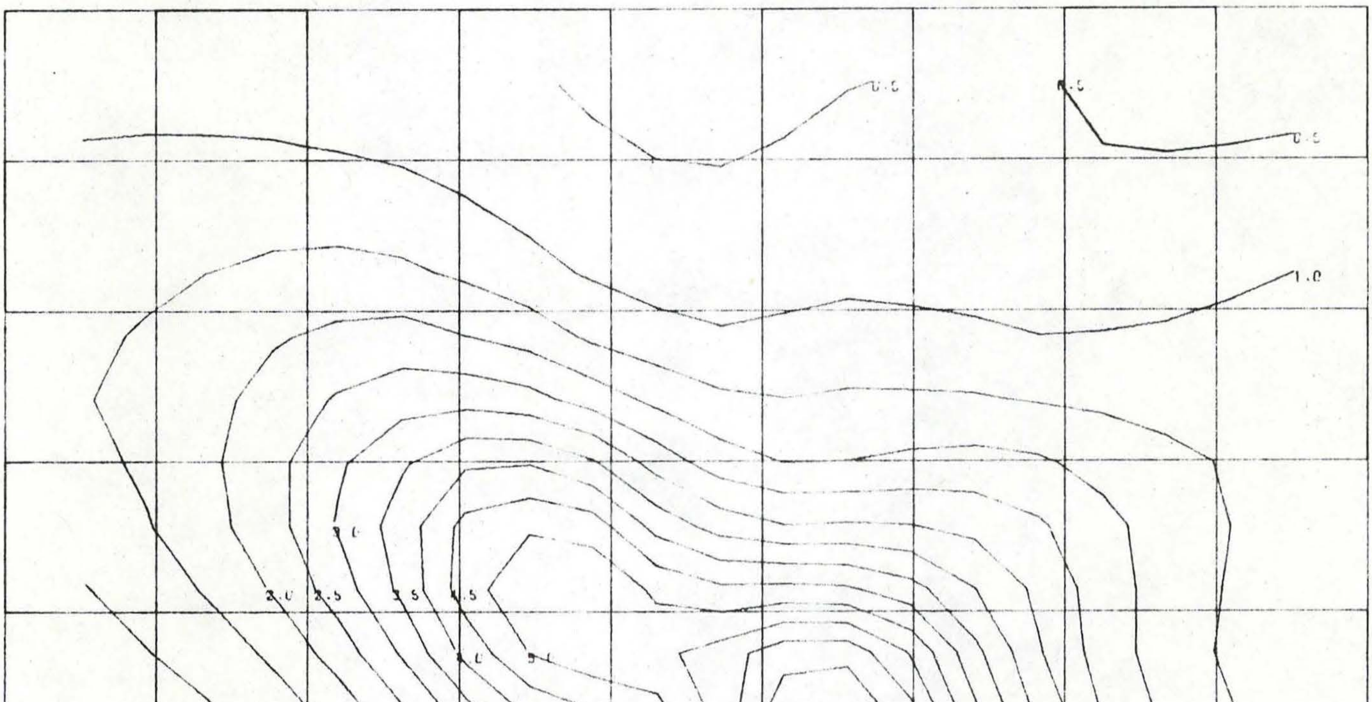


DØUGLAS ANNUAL

Figure A-7a

GILA BEND ANNUAL

Figure A-8a



GLØBE ANNUAL

Figure A-9a

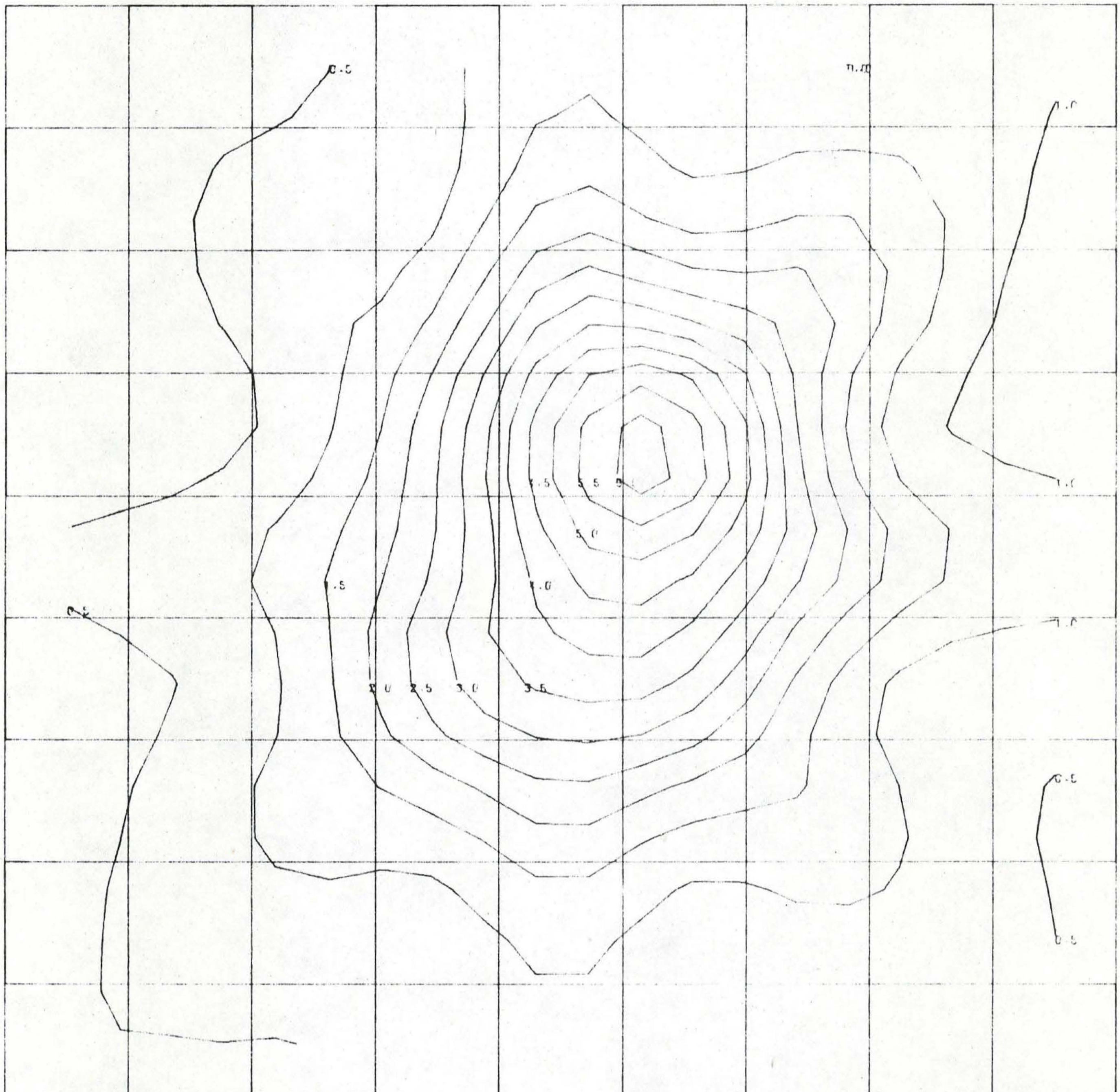
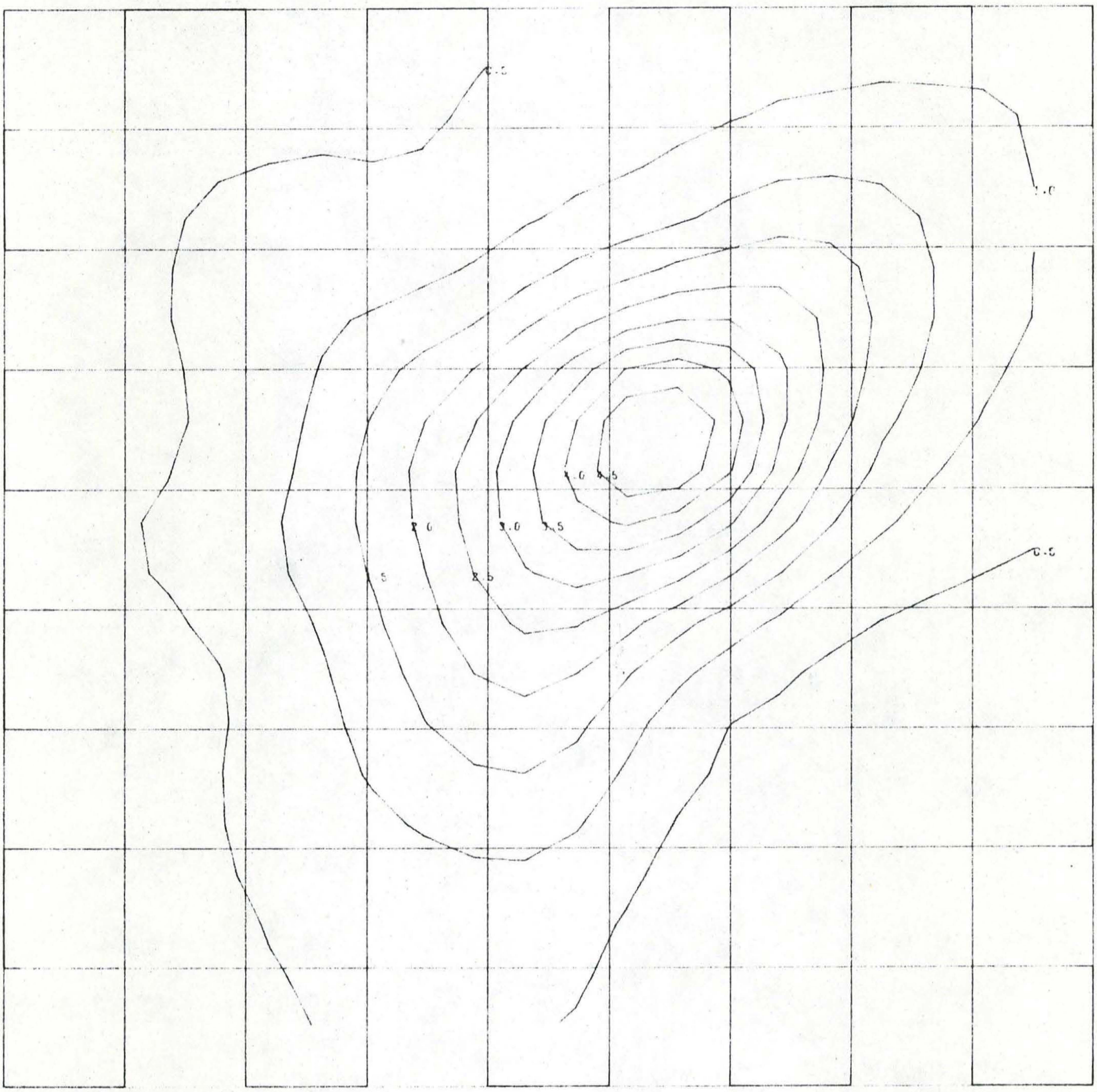
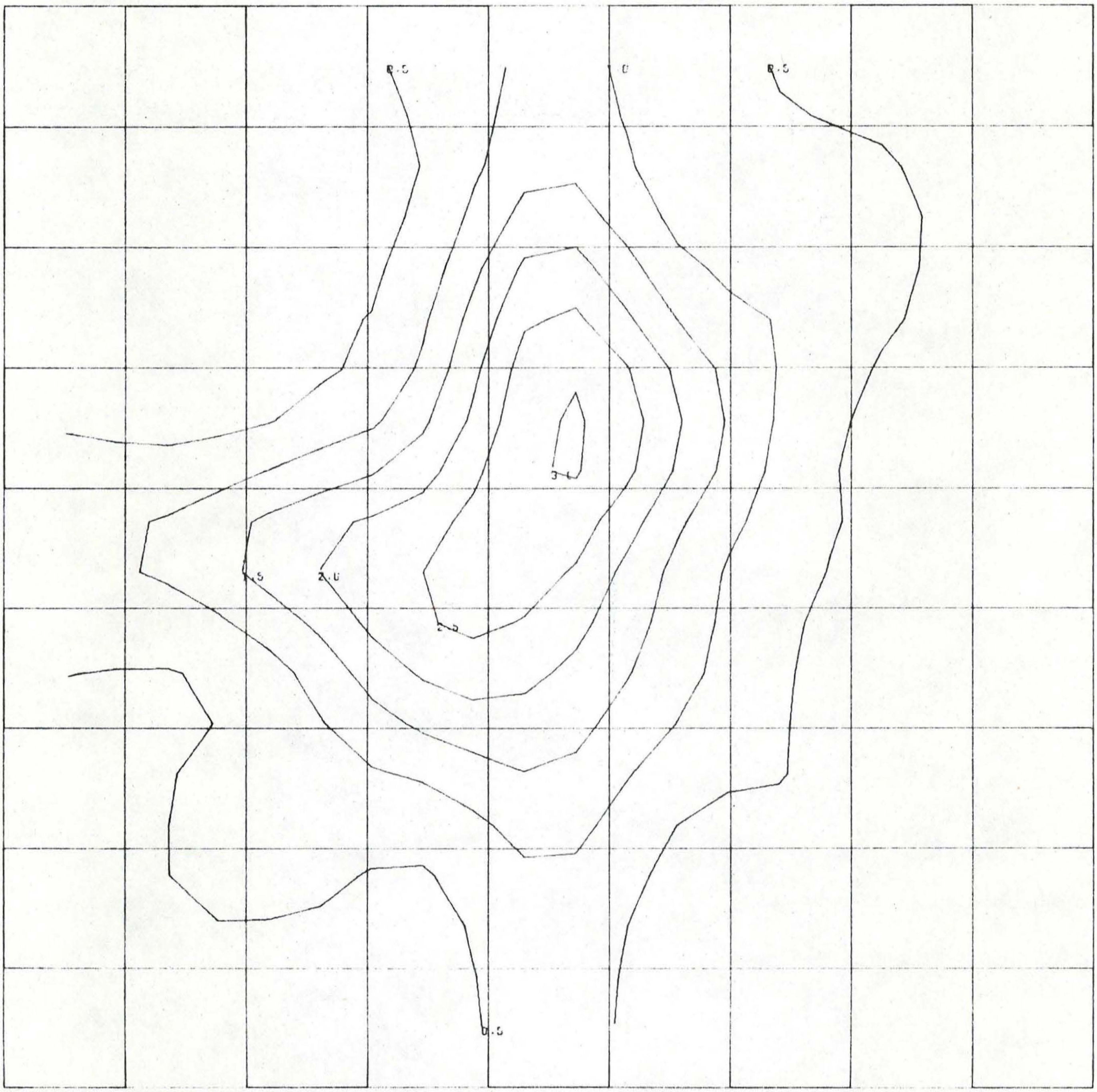


Figure A-10a



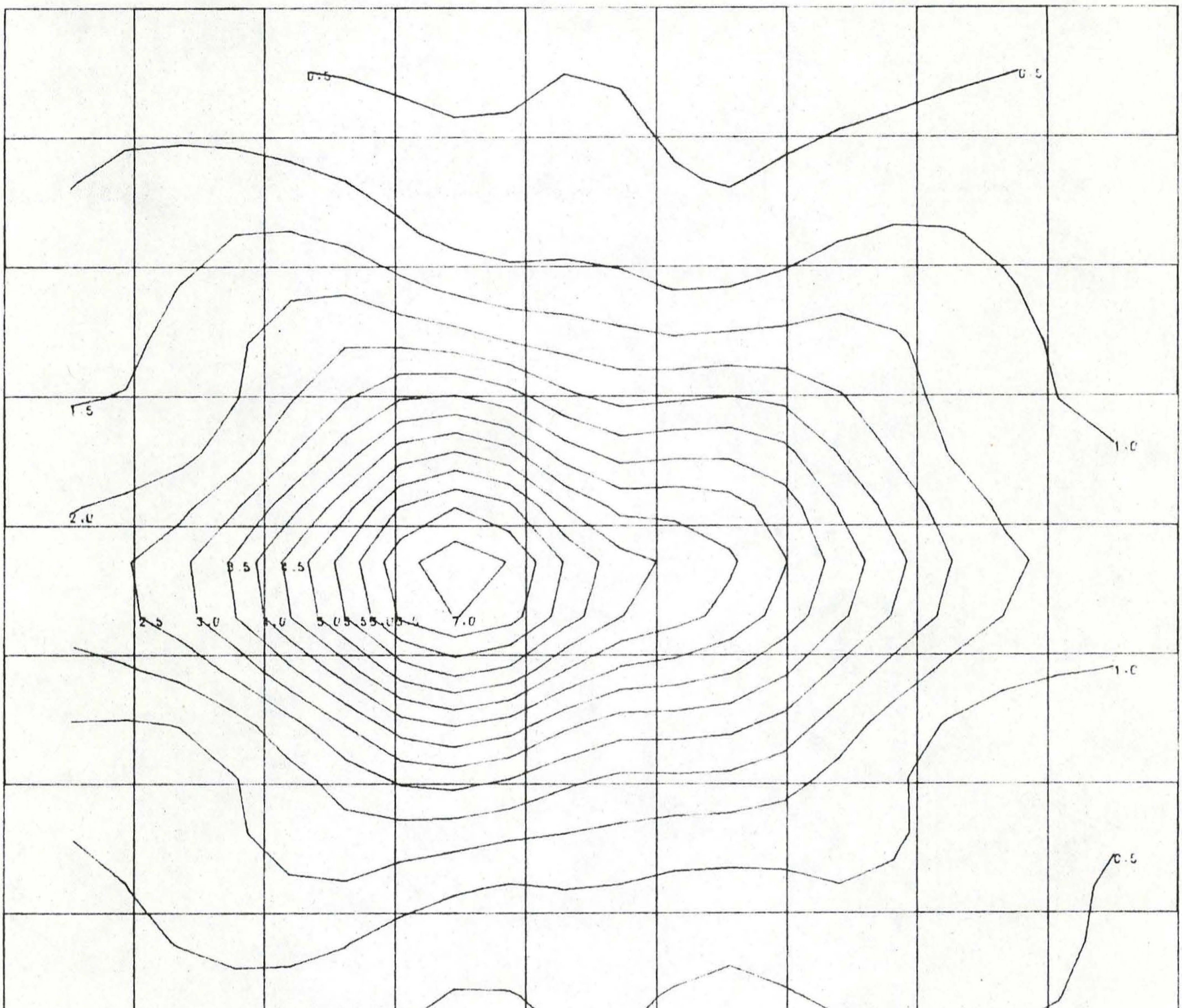
KINGMAN ANNUAL

Figure A-11a



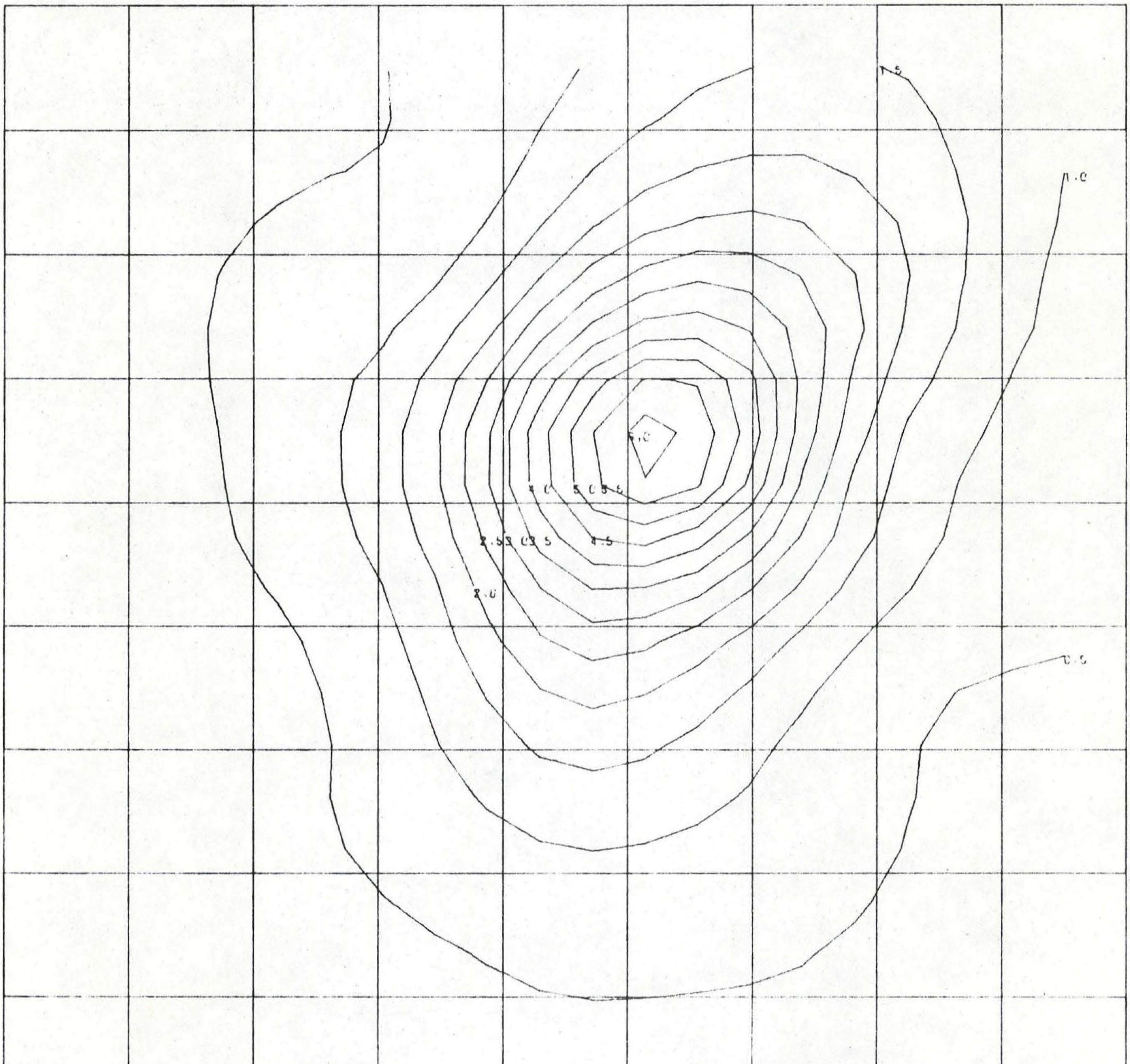
PARK ANNUAL

Figure A-12a



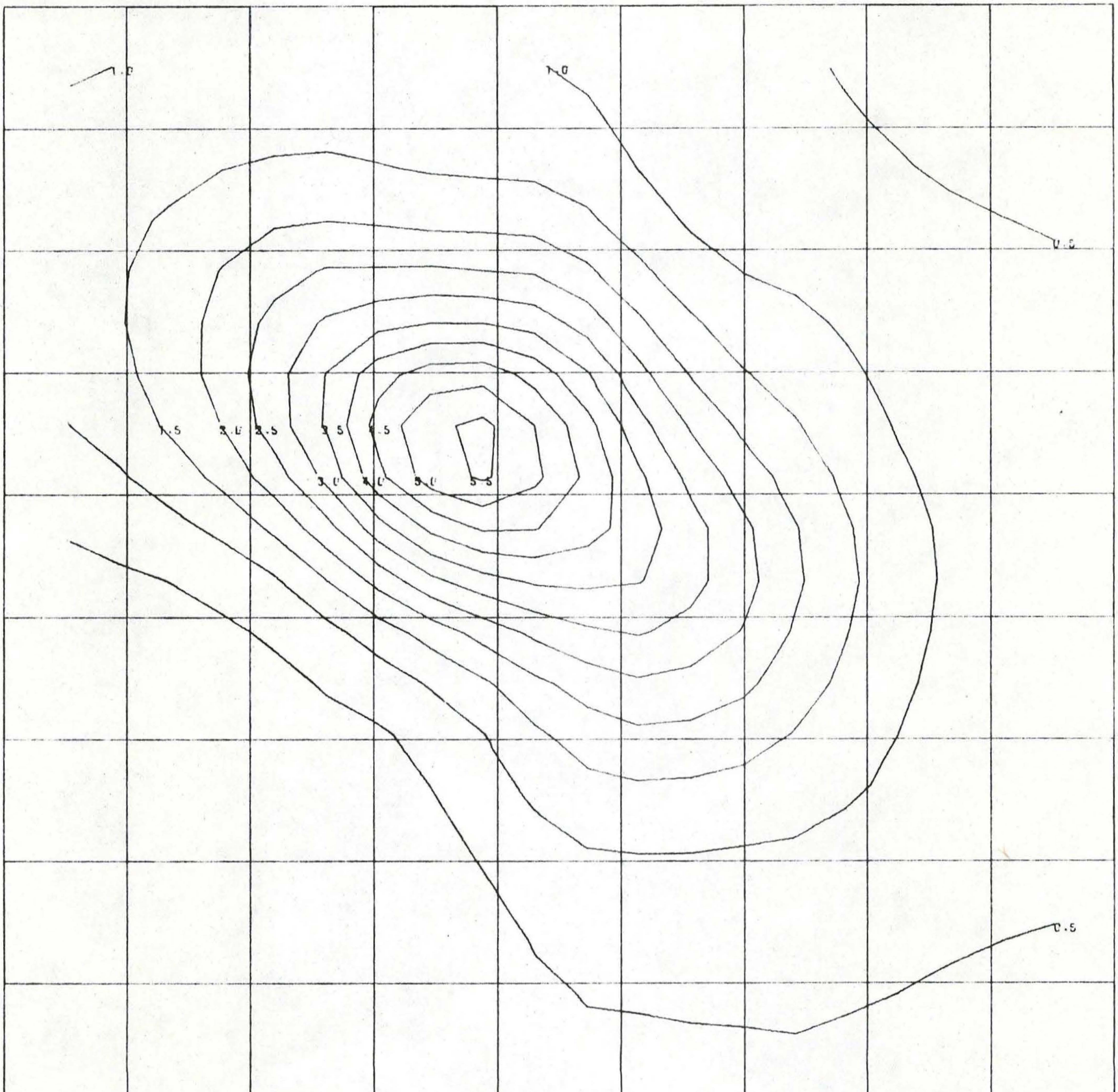
PHOENIX ANNUAL

Figure A-13a



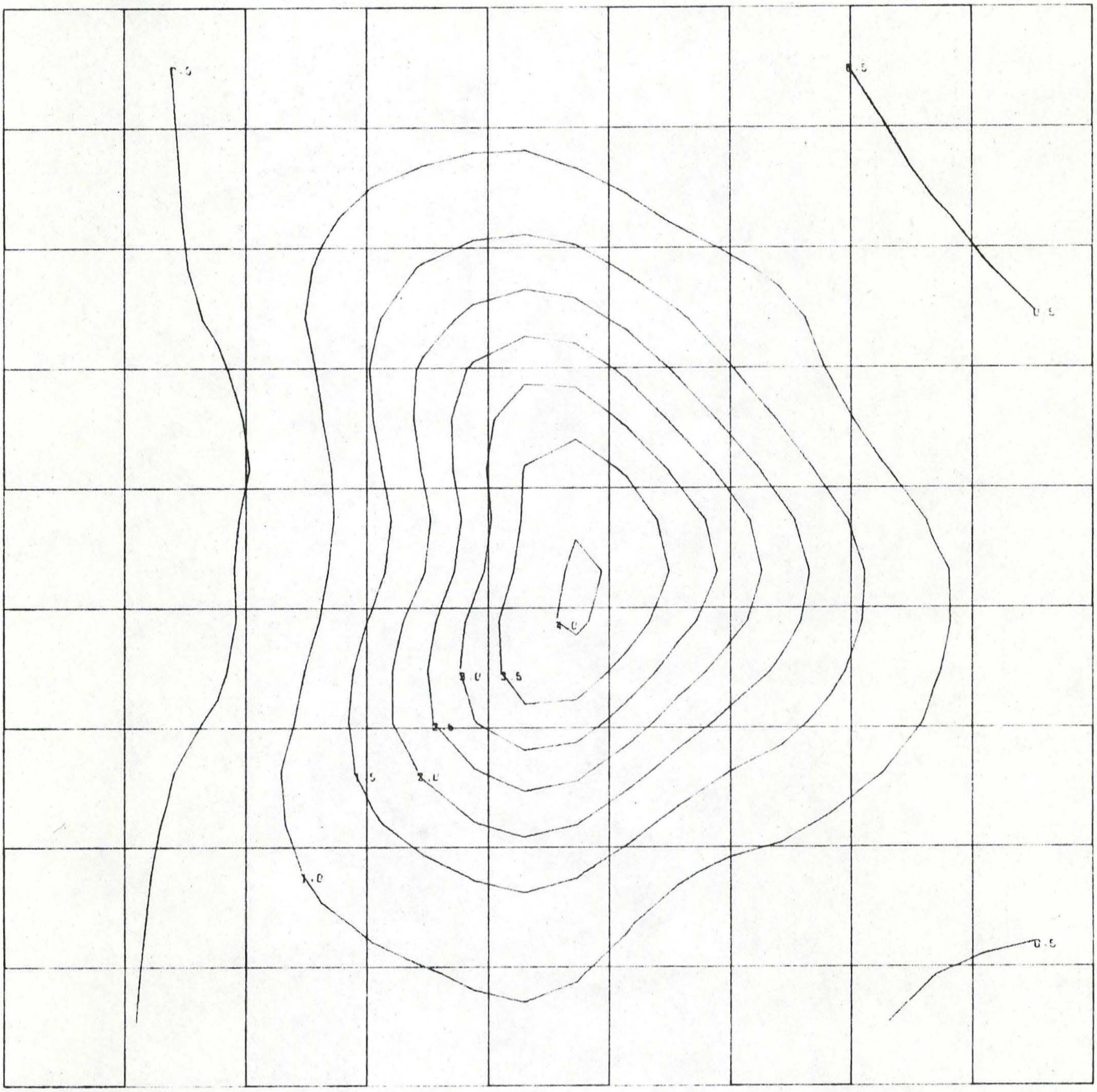
PRESCOTT ANNUAL

Figure A-14a



TUCSON ANNUAL

Figure A-15a



YUMA ANNUAL

Figure A-2b - 15b

Superposition of Figure A-2a - 15a on USGS map.

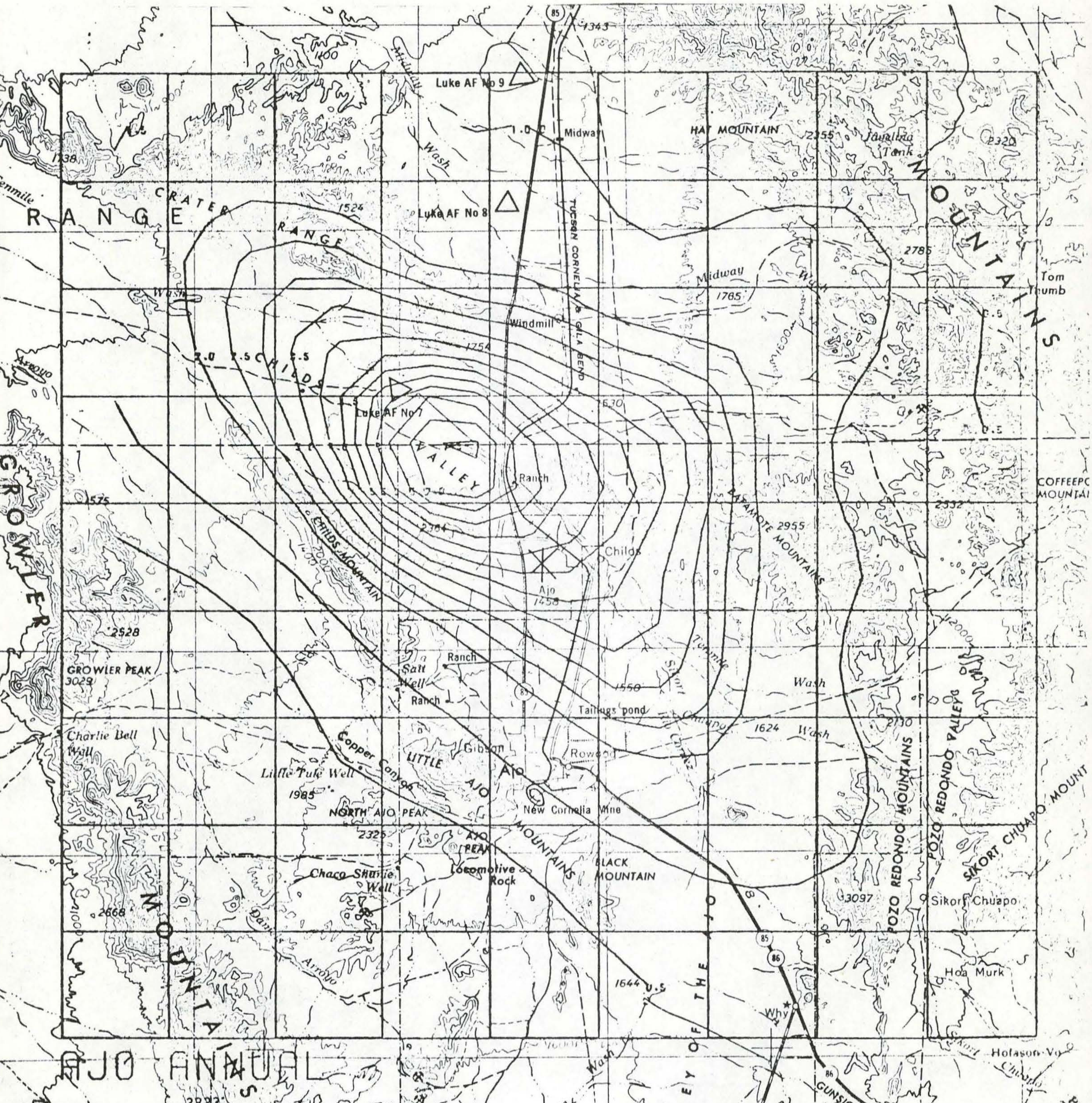
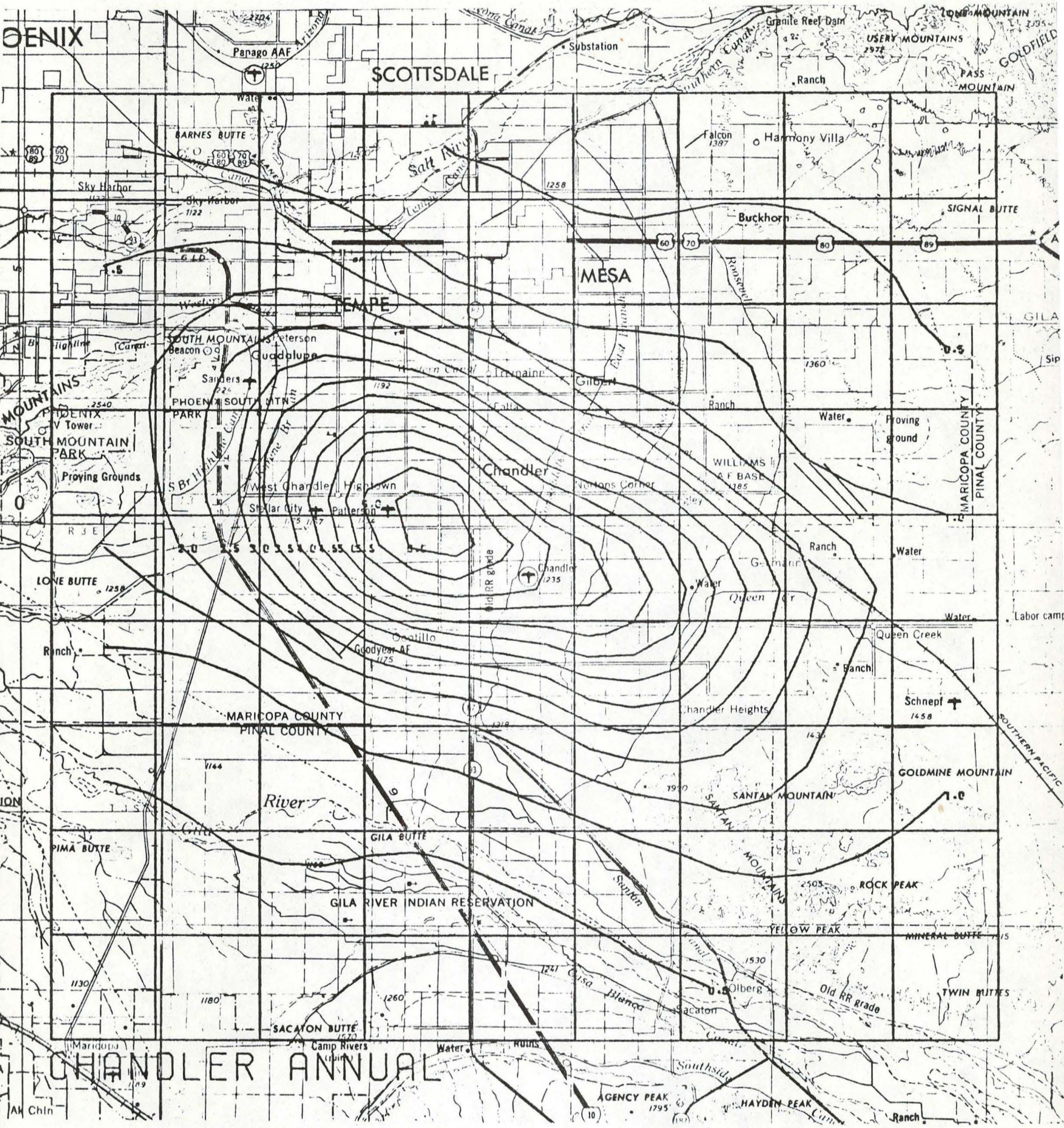

AJO ANNUAL
RANGE
CRATER RANGE
Luke AF No 9
Luke AF No 8
Luke AF No 7
Midway
HAT MOUNTAIN
MOUNTAINS
TUCSON CORNELIA & GILA BEND
Windmill
CHILDS
VALLEY
Ranch
Childs
Ajo
CHILDS MOUNTAIN
BATAMOTE MOUNTAINS
GROWLER
GROWLER PEAK
Charlie Bell Well
Little Tule Well
NORTH AJO PEAK
LITTLE AJO MOUNTAINS
Copper Canyon
Gibson
Salt Well
Tailings pond
Rowood
New Cornelia Mine
BLACK MOUNTAIN
Locomotive Rock
Chaco Shunie Well
POZO REDONDO MOUNTAINS
POZO REDONDO VALLEY
SIKORT CHUAPO MOUNT
Sikort Chuapo
Hoa Murk
Why
COFFEEPC MOUNTAI
Tom Thumb
Jaguima Tank
Wash

Figure A-2b


ROUND MOUNTAIN
MOUNT FLOYD
KAIBAB
NATIONAL
FOREST
Crookton
Corral
Pineveta
Ranch
PICACHO BUTTE
Partridge Canyon
Ash Fork
Corral
Williscraft Dam
Cruice Station
Coconino County
Yavapai County
Cotta Station
HEARST MOUNTAIN
Dare Station
Johnson Canyon
Welch
Sereno Siding
Pine Springs
Rabbit Bill Tank
Meath Dam
Meath Siding
Prairie Station
SOUTH BUTTE
Hell Canyon
Tule Tank
KAIBAB
Camp
PRESCOTT
Farm
Limestone Canyon
NATIONAL
FOREST
Wagon Tire Flat
ASH FORK ANNUAL

Figure A-3b



PHOENIX
SCOTTSDALE
TEMPE
MESA
Chandler
Gilbert
Guadalupe
Buckhorn
Sky Harbor
Panago AAF
Substation
Granite Reef Dam
USERY MOUNTAINS
PASS MOUNTAIN
GOLDFIELD
Harmony Villa
Falcon
Salt River
SIGNAL BUTTE
SOUTH MOUNTAINS
PHOENIX SOUTH MTN PARK
SOUTH MOUNTAIN PARK
Proving Grounds
West Chandler
Stellar City
Patterson
Williams A F BASE
Nortons Corner
Proving ground
MARICOPA COUNTY
PINAL COUNTY
Queen Creek
Chandler Heights
Goodyear AF
Ocotillo
LONE BUTTE
GILA BUTTE
GILA RIVER INDIAN RESERVATION
SANTAN MOUNTAIN
GOLDMINE MOUNTAIN
SOUTHERN PACIFIC
ROCK PEAK
YELLOW PEAK
MINERAL BUTTE
TWIN BUTTES
Olberg
Sacaton
Casa Blanca
SACATON BUTTE
AGENCY PEAK
HAYDEN PEAK
PIMA BUTTE
Schnepf
Labor camp
CHANDLER ANNUAL

Figure A-4b

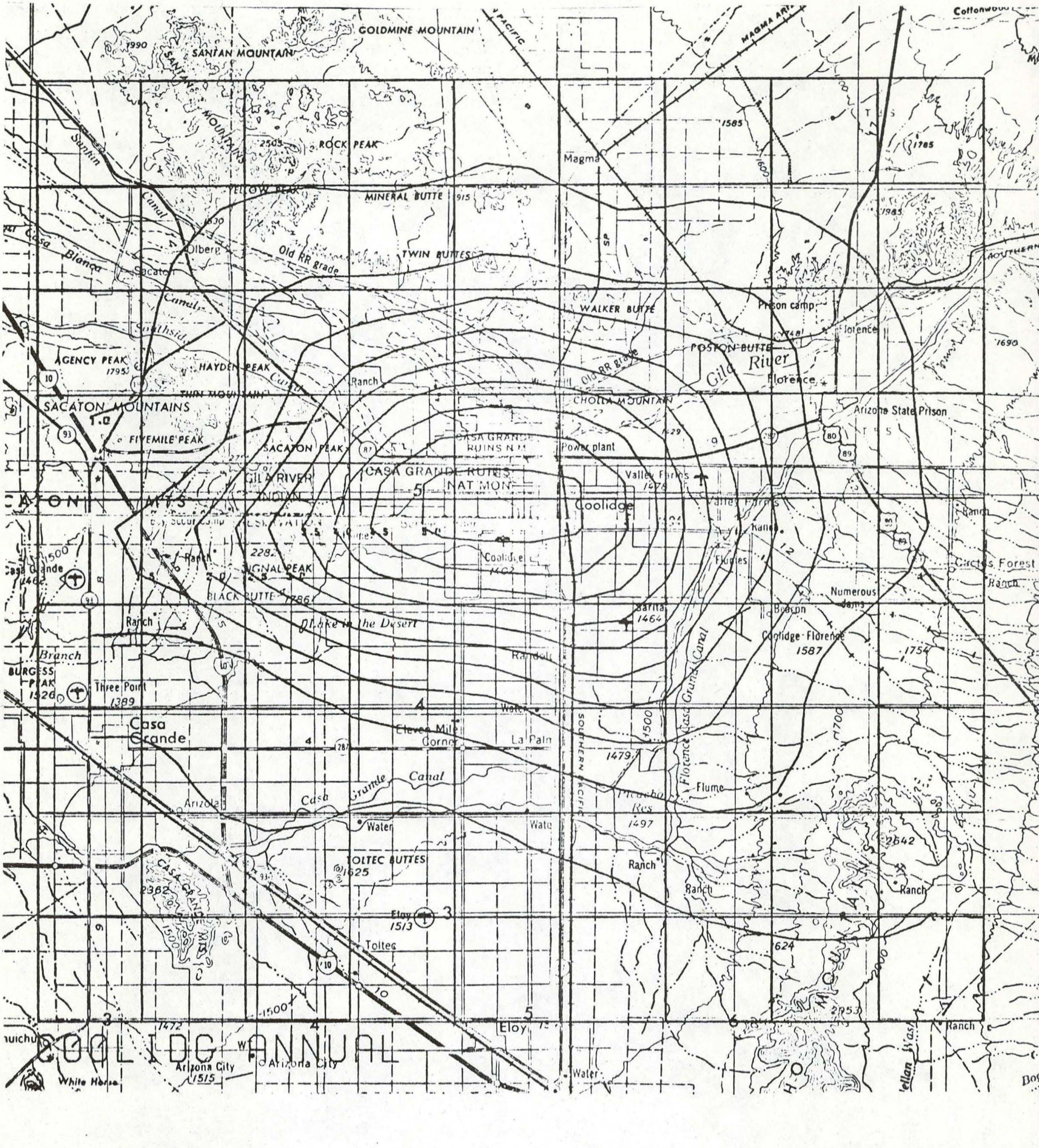
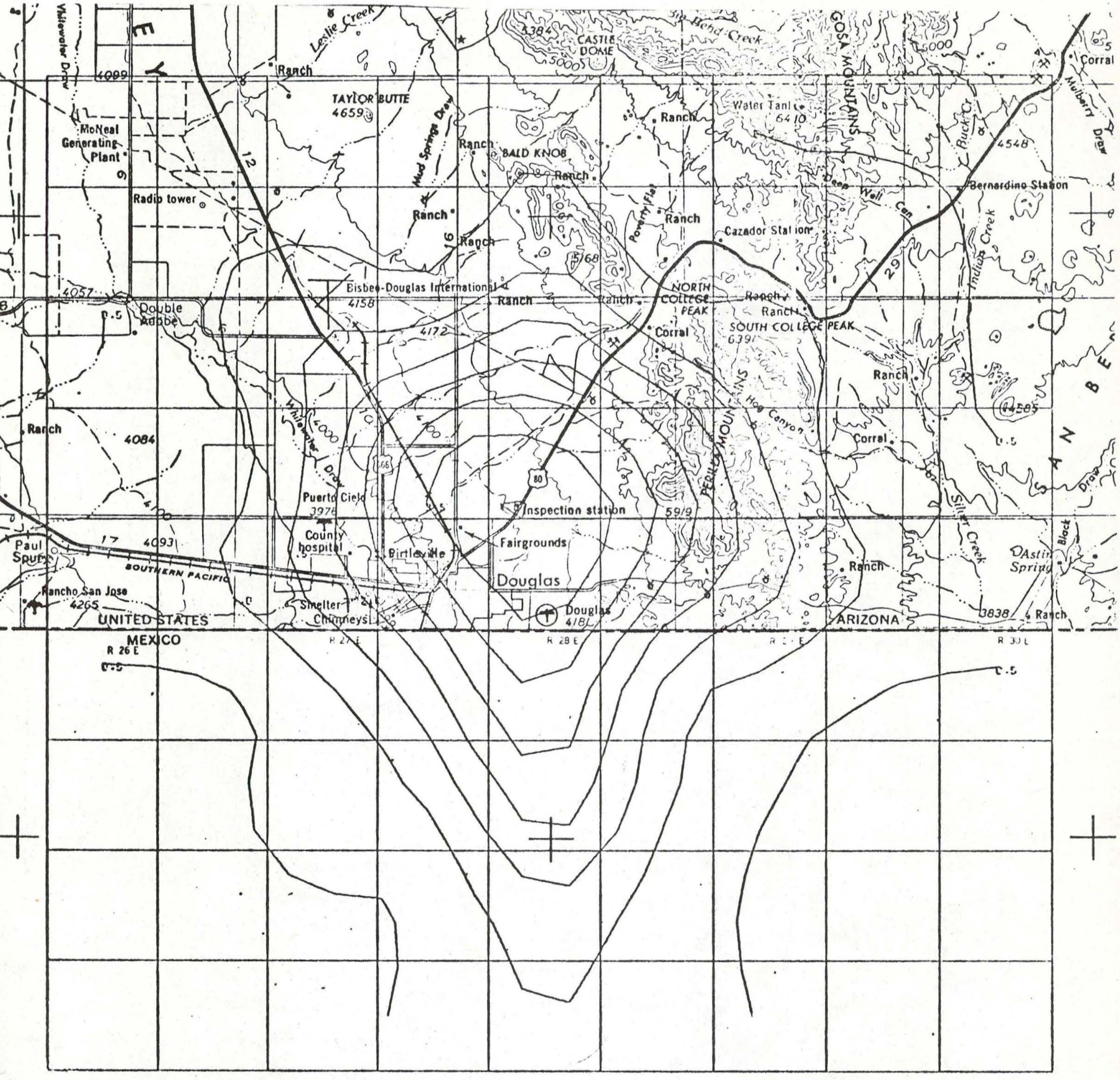

GOLDMINE MOUNTAIN
SANTAN MOUNTAIN
ROCK PEAK
MINERAL BUTTE
TWIN BUTTES
Magma
WALKER BUTTE
Prison camp
POSTON BUTTE
Gila River
Florence
AGENCY PEAK
HAYDEN PEAK
SACATON MOUNTAINS
FIVEMILE PEAK
SACATON PEAK
CHOLLA MOUNTAIN
Arizona State Prison
CASA GRANDE RUINS NAT MON
Power plant
Valley Farms
Coolidge
GILA RIVER
SIGNAL PEAK
BLACK BUTTE
Lake in the Desert
Sacaton
Olberg
Casa Blanca
Canal
Old RR grade
Casa Grande
Three Point
BURGESS PEAK
Branch
Ranch
Randolph
Sarita
Coolidge-Florence
Numerous dams
Circle S Forest Ranch
Eleven Mile Corner
La Palma
Casa Grande Canal
Picacho Res
Flume
Florence Casa Grande Canal
SOUTHERN PACIFIC
Arizola
Water
TOLTEC BUTTES
Eloy
Toltec
CASA GRANDE MTS
Arizona City
White Horse
COOLIDGE ANNUAL

Figure A-5b



DOUGLAS ANNUAL

Figure A-6b

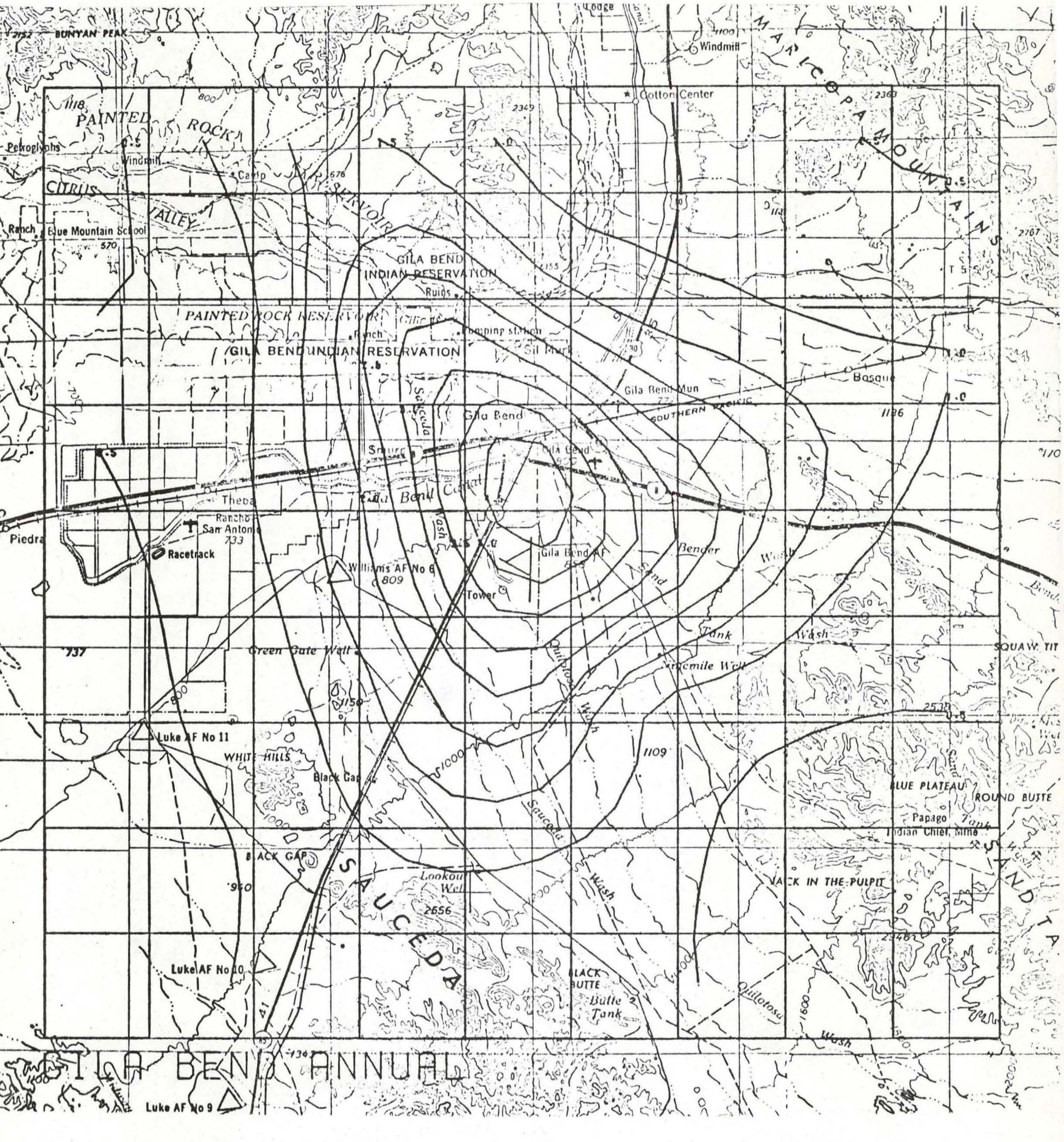

GILA BEND ANNUAL
MARICOPA MOUNTAINS
PAINTED ROCK
CITRUS VALLEY
Blue Mountain School
GILA BEND INDIAN RESERVATION
PAINTED ROCK RESERVOIR
Cotton Center
Windmill
Petroglyphs
Ranch
Ruins
Pumping station
Gila Bend
Gila Bend Mun
SOUTHERN PACIFIC
Bosque
Theba
Rancho San Antonio
733
Racetrack
Piedra
Gila Bend Canal
Williams AF No 6
809
Gila Bend AF
Bender
Tower
Sand
Tank
Wash
Green Gate Well
SQUAW TIT
Luke AF No 11
WHITE HILLS
Black Gap
BLACK GAP
1109
BLUE PLATEAU
ROUND BUTTE
Papago Indian Chief Mine
JACK IN THE PULPIT
SAUCEDA
Lookout Well
2556
Luke AF No 10
BLACK BUTTE
Butte Tank
Quilotosa
Luke AF No 9
BUNYAN PEAK
2349
2363
2767
1136
737
940
1000
1150
1200
1600
1343

Figure A-7b

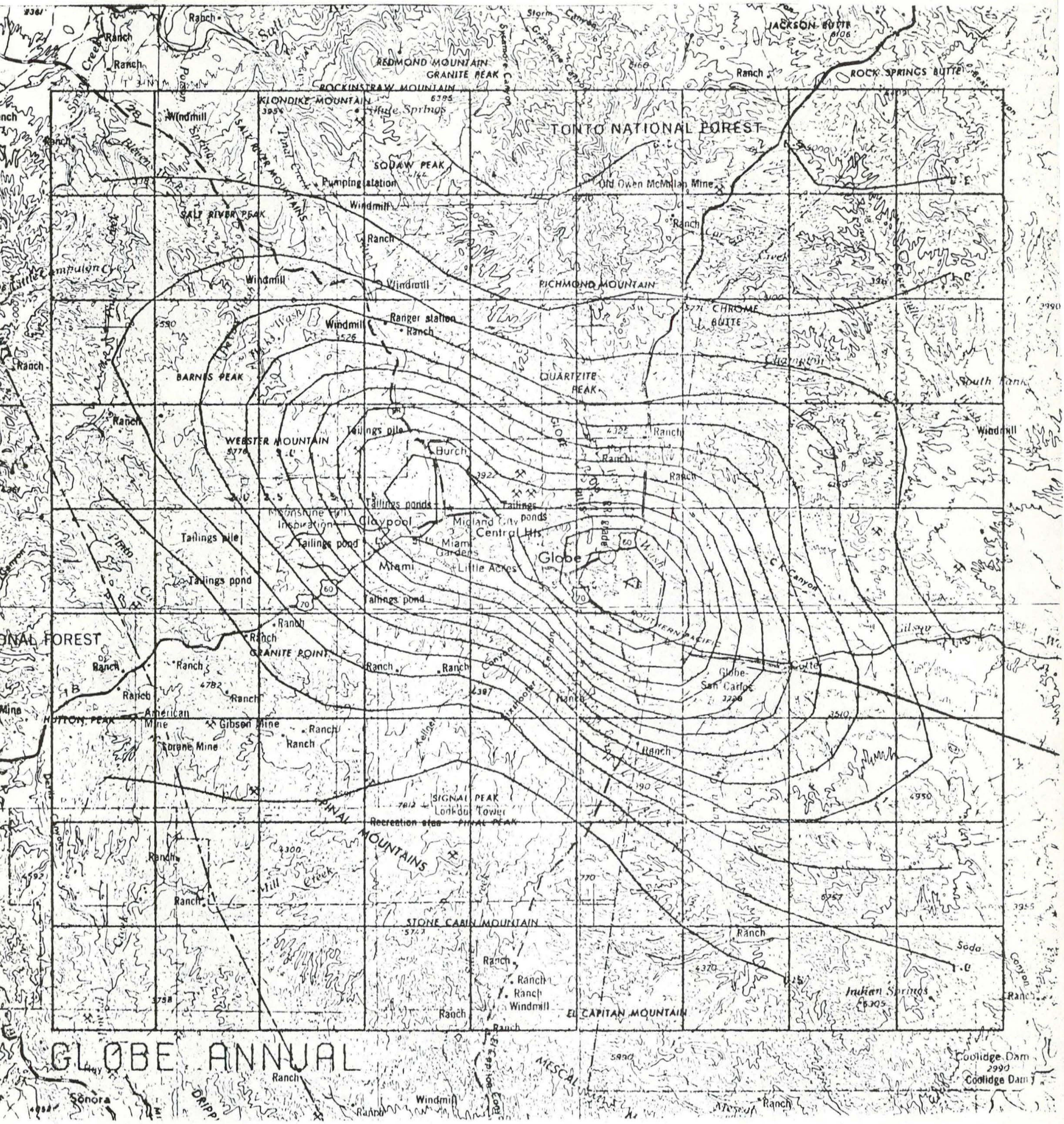
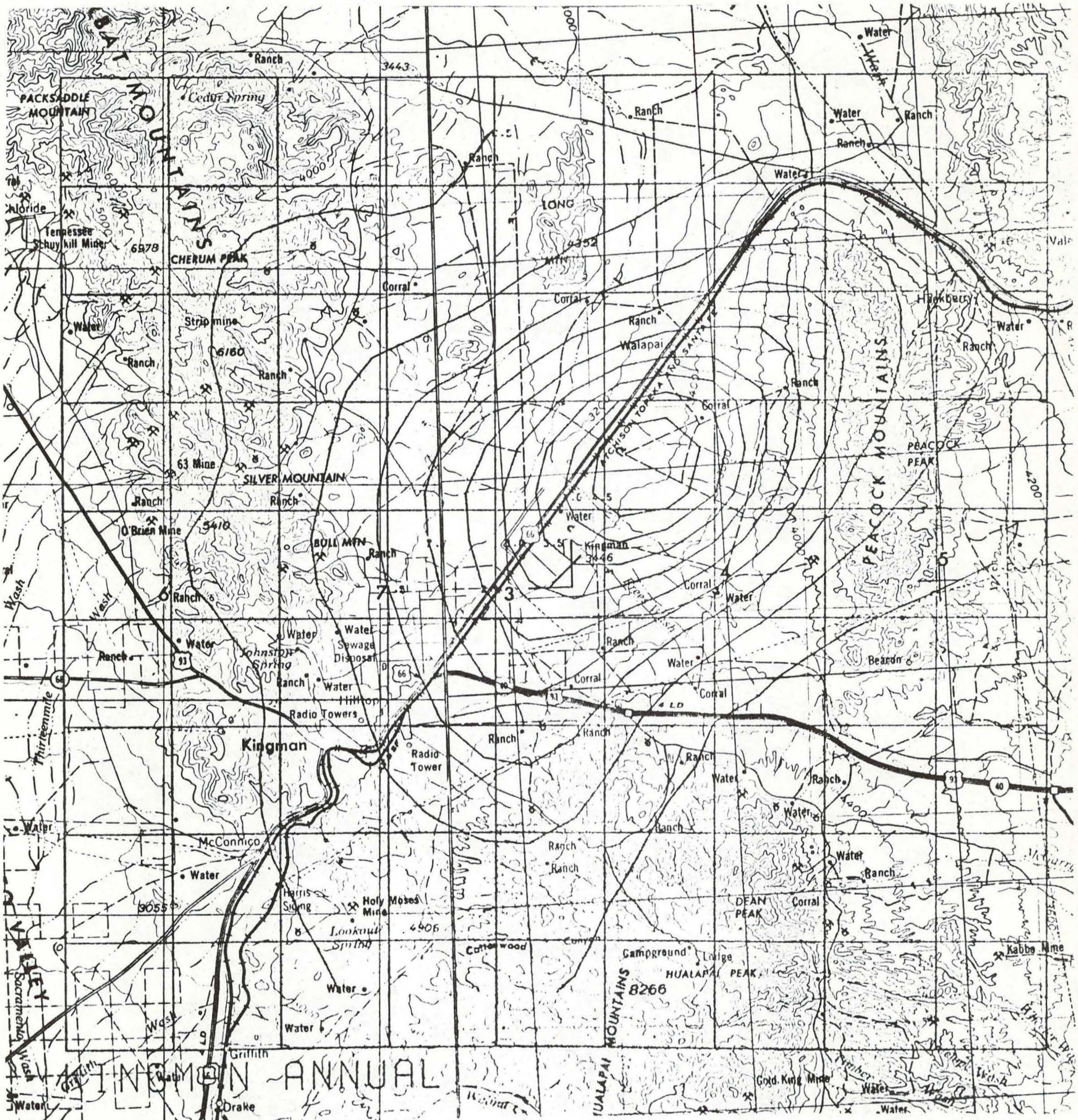

GLOBE ANNUAL
TONTO NATIONAL FOREST
JACKSON BUTTE
ROCK SPRINGS BUTTE
REDMOND MOUNTAIN
GRANITE PEAK
ROCKINSTRAW MOUNTAIN
KLONDIKE MOUNTAIN
SODAW PEAK
Pumping station
Old Owen McMillan Mine
SALT RIVER PEAK
SALT RIVER MOUNTAINS
RICHMOND MOUNTAIN
CHROME BUTTE
Ranger station
BARNES PEAK
QUARTZITE PEAK
WEBSTER MOUNTAIN
Tailings pile
Burch
Tailings ponds
Claypool
Midland City
Central Hts
Miami
Miami Gardens
Little Acres
Globe
Tailings pond
SOUTHERN PACIFIC
Globe-San Carlos
GRANITE POINT
HUTTON PEAK
American Mine
Gibson Mine
Cochrane Mine
SIGNAL PEAK
Lookout Tower
Recreation area
PINAL MOUNTAINS
Mill Creek
STONE CABIN MOUNTAIN
EL CAPITAN MOUNTAIN
Indian Springs
Coolidge Dam
MESCAL
Sonora
Windmill
Ranch

Figure A-8b


Castor Temple
Osiris Temple
Tower of Set
Vesta Temple
The Battleship
Hermits Rest
O'NEILL BUTTE
Angels Gate
Vishnu Temple
Solomon Temple
Jupiter Temple
Venus Temple
Apollo Temple
Cape Royal
Wotans Throne
HORSESHOE MESA
Zuni Point
Papago Point
Grandview Point
GRAND CANYON NATIONAL PARK
Lookout tower
7531
FOREST
6215
6180
6000
Ranch
Corral
Camp
Tusayan
Grand Canyon National Park
6605
KAIBAB NATIONAL FOREST
KAIBAB NATION
5931
Anita Station
RED BUTTE
7324
HOWARD HILL
Corral
Water
6900
Willaha
GRAND CANYON ANNUAL
6665
DOUBLE KT

Figure A-9b



BAT MOUNTAINS
PACKSADDLE MOUNTAIN
Cedar Spring
Ranch
3443
Chloride
Tennessee Schuylkill Mine
6978
CHERUM PEAK
LONG MTN
4352
Corral
Strip mine
6160
Ranch
Water
Walapai
Hackberry
PEACOCK MOUNTAINS
PEACOCK PEAK
63 Mine
SILVER MOUNTAIN
O'Brien Mine
5410
BULL MTN
Kingman 3446
Johnston Spring
Sewage Disposal
Hilltop
Radio Towers
Kingman
Radio Tower
McConnico
Harris Siding
Holy Moses Mine
Lookout Spring
4906
Cottonwood
Campground
Lodge
HUALAPAI PEAK
8266
DEAN PEAK
Beacon
Kabba Mine
HUALAPAI MOUNTAINS
Thirteenmile
Sacramento Wash
Griffith
Drake
Gold King Mine
KINGMAN ANNUAL

Figure A-10b

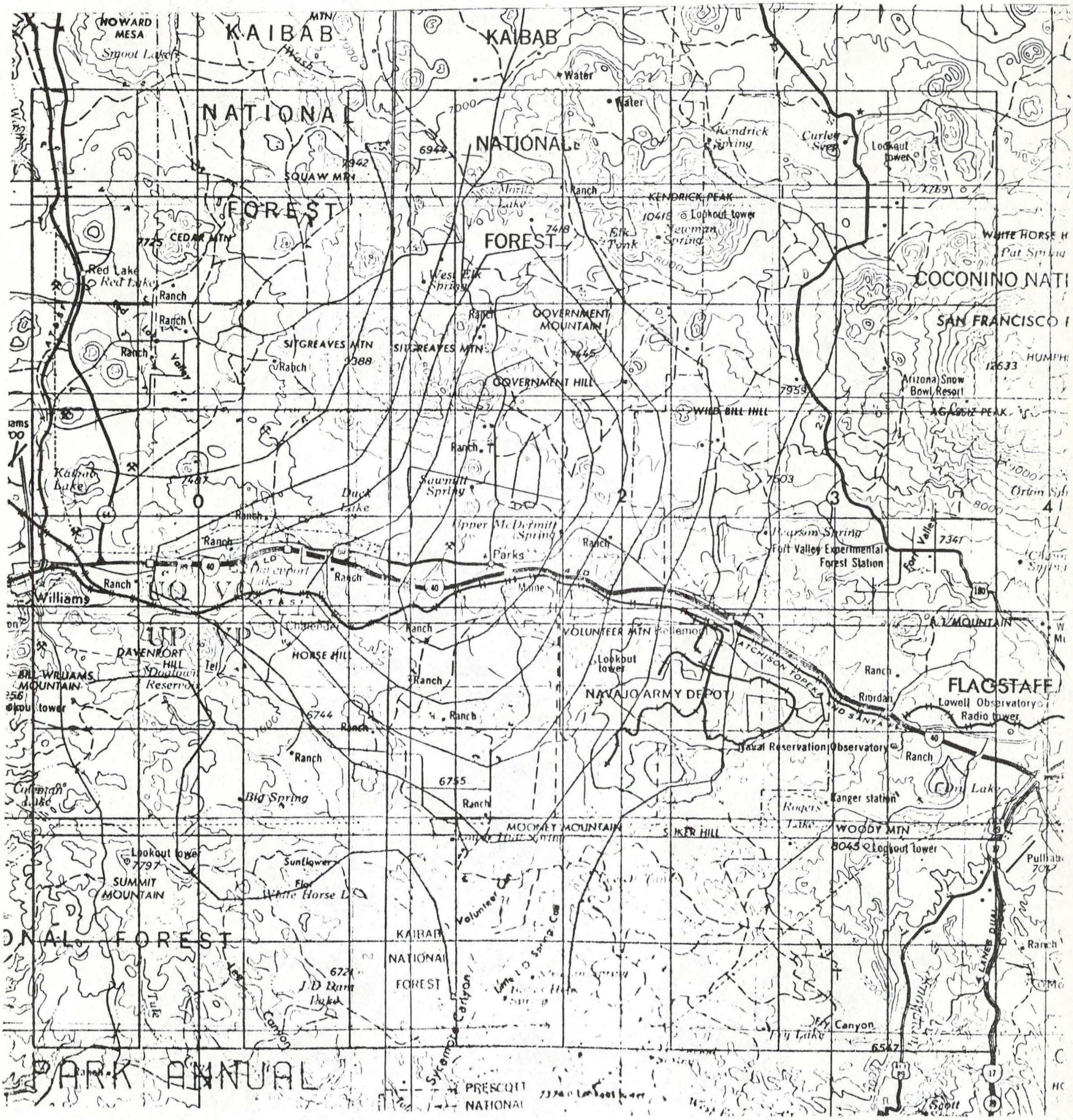

HOWARD MESA
Smoot Lake
KAIBAB
KAIBAB
NATIONAL
NATIONAL
FOREST
FOREST
Water
Water
SQUAW MTN
7942
6944
7000
Kendrick Spring
Curley Seep
Lookout tower
Moritz Lake
Ranch
KENDRICK PEAK
10418
Lookout tower
Newman Spring
Elk Tank
7418
7725
CEDAR MTN
Red Lake
Red Lake
Ranch
Ranch
Ranch
Ranch
West Elk Spring
WHITE HORSE
Pat Spring
COCONINO NATI
SAN FRANCISCO
GOVERNMENT MOUNTAIN
SITGREAVES MTN
SITGREAVES MTN
9388
7645
HUMPH
12633
Arizona Snow Bowl Resort
GOVERNMENT HILL
7959
WILD BILL HILL
AGASSIZ PEAK
Kaibab Lake
Ranch
7467
Sawmill Spring
Duck Lake
7503
Orion Spring
0
2
3
4
8000
9000
Upper McDermitt Spring
Pearson Spring
Fort Valley Experimental Forest Station
Fort Valley
7341
Parks
Davenport Lake
Williams
Maine
Challender
VOLUNTEER MTN
Bellemont
A-1 MOUNTAIN
DAVENPORT HILL
HORSE HILL
Lookout tower
Dogtown Reservoir
BILL WILLIAMS MOUNTAIN
Lookout tower
ATCHISON TOPEKA AND SANTA FE
Ranch
FLAGSTAFF
Riordan
Lowell Observatory
Radio tower
NAVAJO ARMY DEPOT
6744
Ranch
Ranch
Naval Reservation
Observatory
Ranch
6755
Big Spring
Ranger station
Rogers Lake
Ranch
MOONEY MOUNTAIN
SIKER HILL
WOODY MTN
8045
Lookout tower
Lookout tower
7797
Sunflower Flat
White Horse L
SUMMIT MOUNTAIN
Volunteer
NAL FOREST
KAIBAB NATIONAL FOREST
J D Dam Lake
Sycamore Canyon
Fry Canyon
Fry Lake
6567
Ranch
PARK ANNUAL
PRESCOTT NATIONAL
Scott
40
89
17
180

Figure A-11b

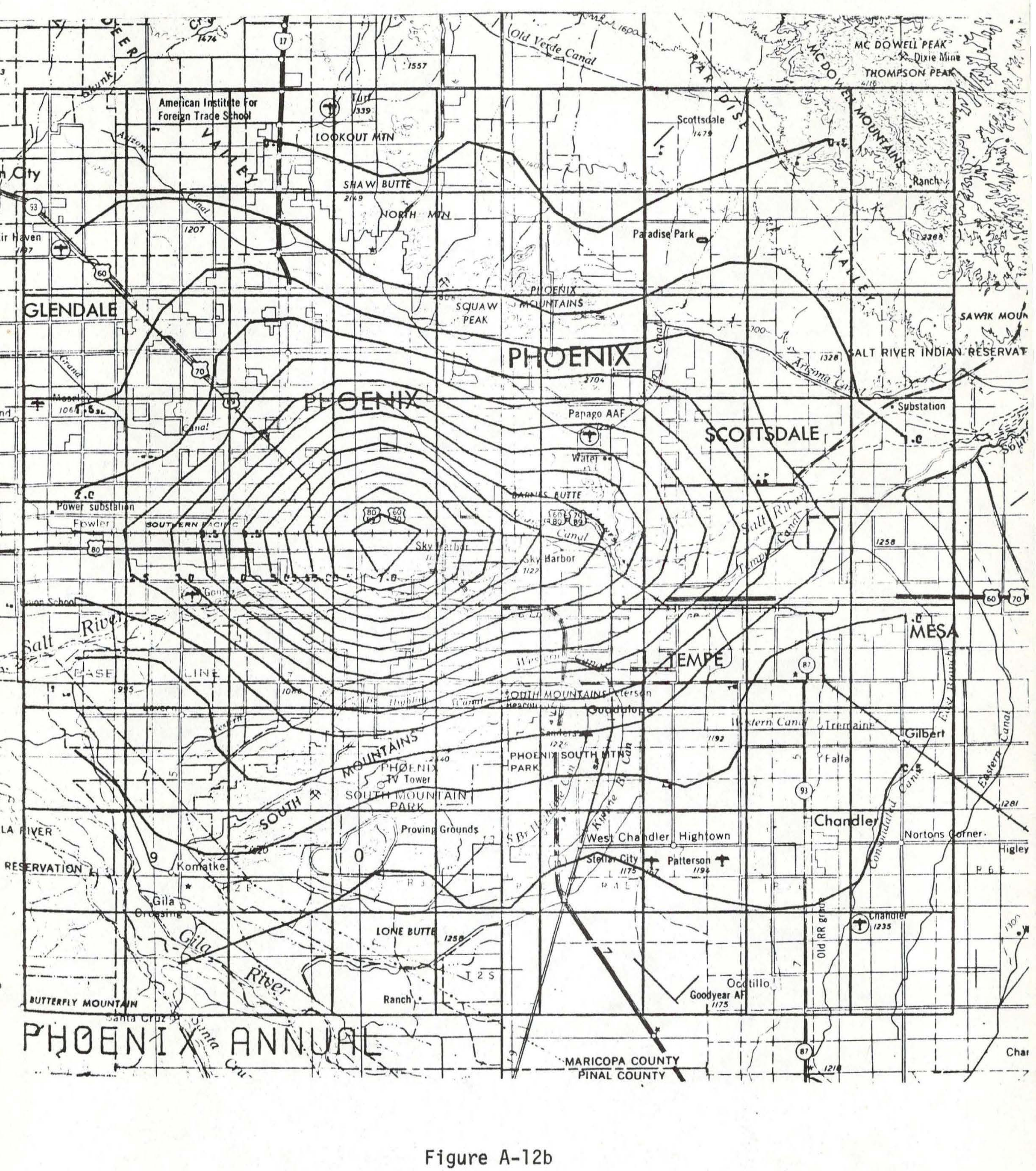

PHOENIX ANNUAL
PHOENIX
GLENDALE
SCOTTSDALE
TEMPE
MESA
Chandler
Gilbert
American Institute For Foreign Trade School
LOOKOUT MTN
SHAW BUTTE
NORTH MTN
SQUAW PEAK
PHOENIX MOUNTAINS
Papago AAF
Sky Harbor
SOUTH MOUNTAINS
PHOENIX SOUTH MTN PARK
SOUTH MOUNTAIN PARK
Proving Grounds
LONE BUTTE
West Chandler
Hightown
Stellar City
Patterson
Goodyear AF
Ocotillo
Komatke
Gila Crossing
Gila River
Salt River
BUTTERFLY MOUNTAIN
MARICOPA COUNTY
PINAL COUNTY
MC DOWELL PEAK
THOMPSON PEAK
MC DOWELL MOUNTAINS
PARADISE VALLEY
Paradise Park
SALT RIVER INDIAN RESERVAT
Power substation
Fowler
Tremaine
Falfa
Nortons Corner
Higley
7.0

Figure A-12b

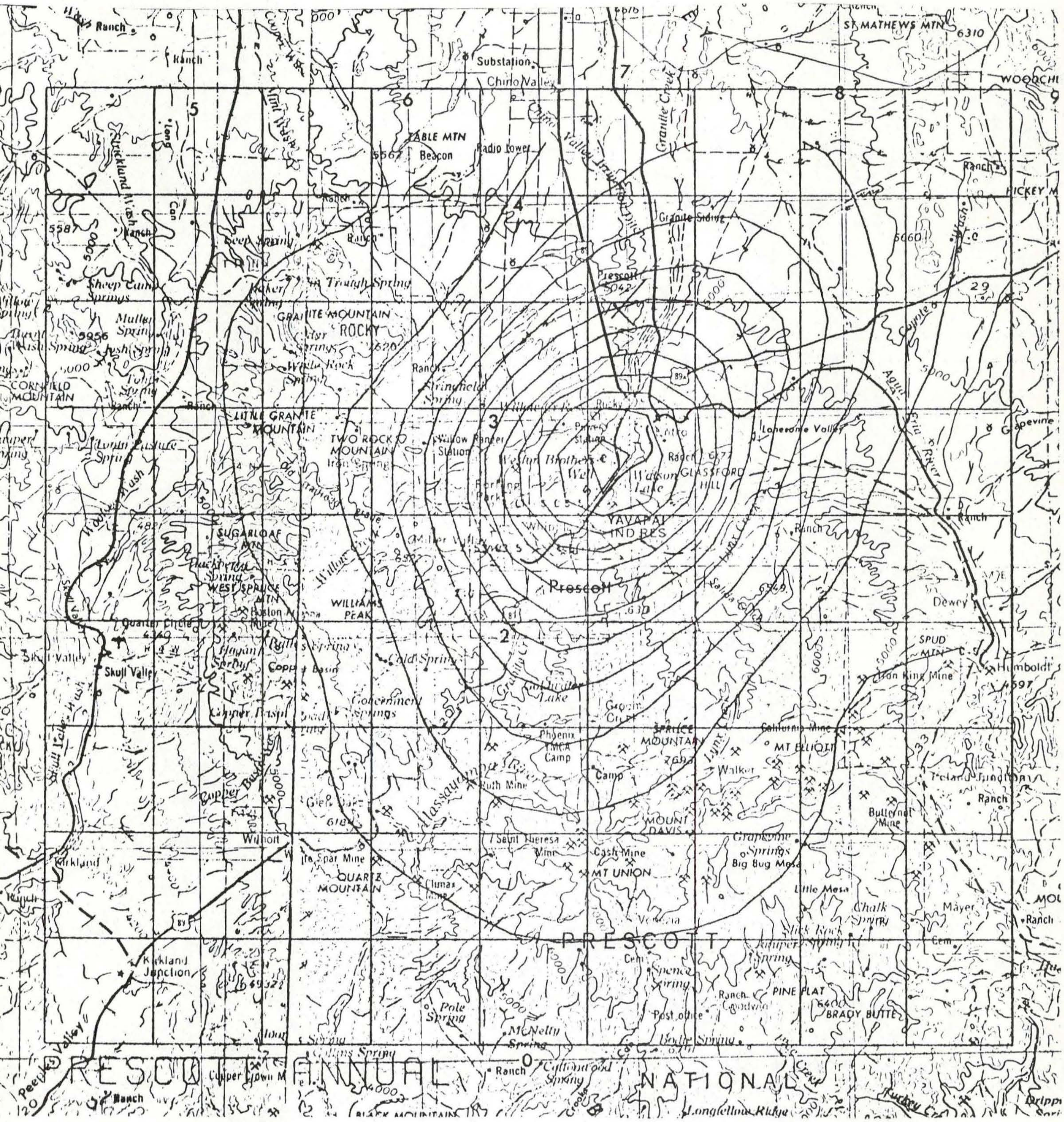


Figure A-13b

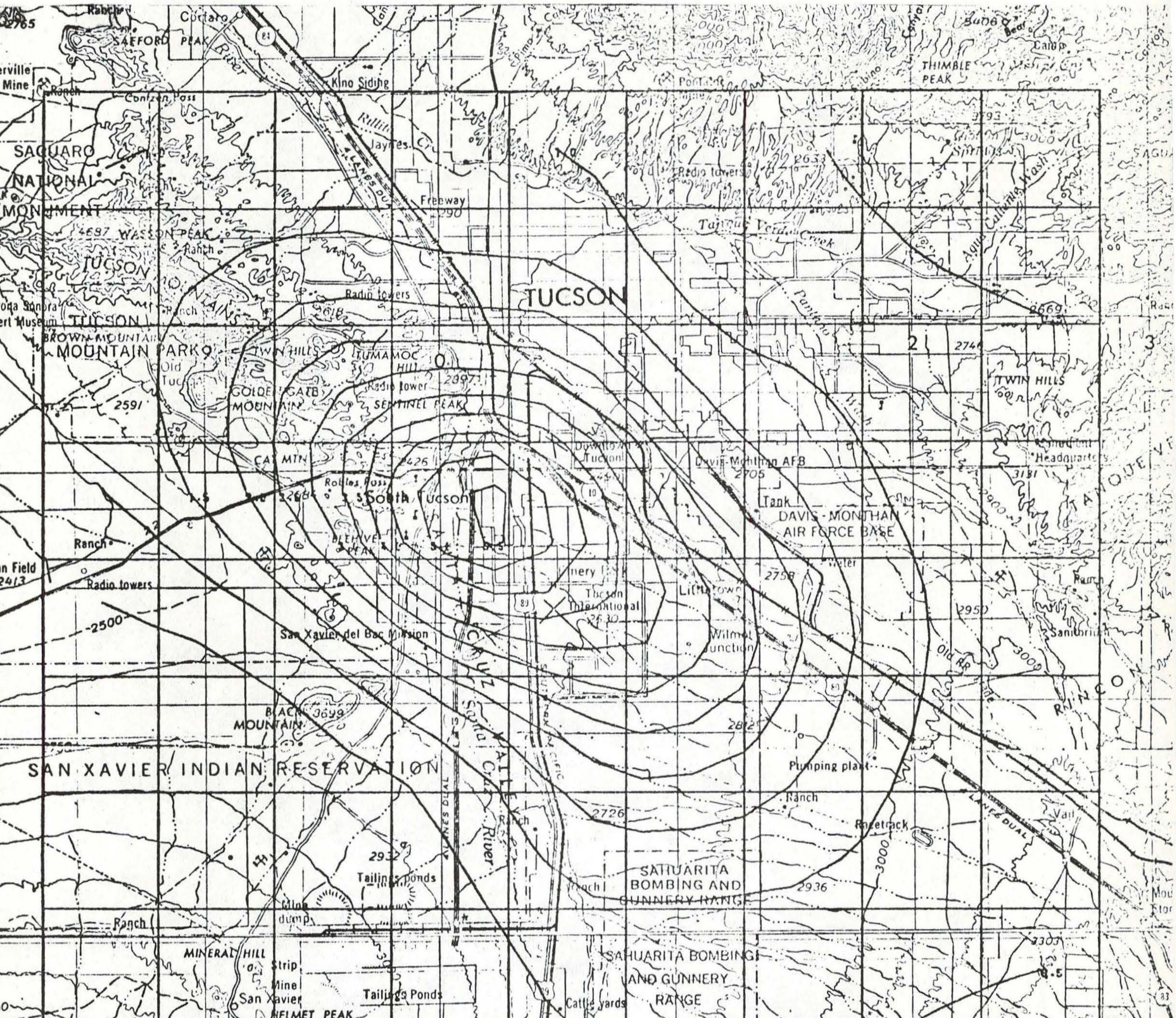

TUCSON
SAGUARO NATIONAL MONUMENT
TUCSON MOUNTAIN PARK
SAN XAVIER INDIAN RESERVATION
DAVIS-MONTHAN AIR FORCE BASE
SAHUARITA BOMBING AND GUNNERY RANGE
South Tucson
Downtown Tucson
Tucson International
San Xavier del Bac Mission
BLACK MOUNTAIN
SENTINEL PEAK
TUMAMOC HILL
GOLDEN GATE MOUNTAIN
CAT MTN
WASSON PEAK
SAFFORD PEAK
THIMBLE PEAK
MINERAL HILL
HELMET PEAK
SAMANIEGO PEAK
MT FAGAN
TWIN BUTTES
Twin Buttes
Sahuarita
Kino Siding
Jaynes
Cortaro
Freeway
Radio towers
Tailings ponds
Pumping plant
Racetrack
Cattle yards
Wilmot Junction
Littletown
SOUTHERN PACIFIC
Santa Cruz River
Rillito Cr
Tanque Verde Creek
Pantano Wash
Agua Caliente Wash
2500
2726
2812
2936
3000
TUCSON ANNUAL

Figure A-14b

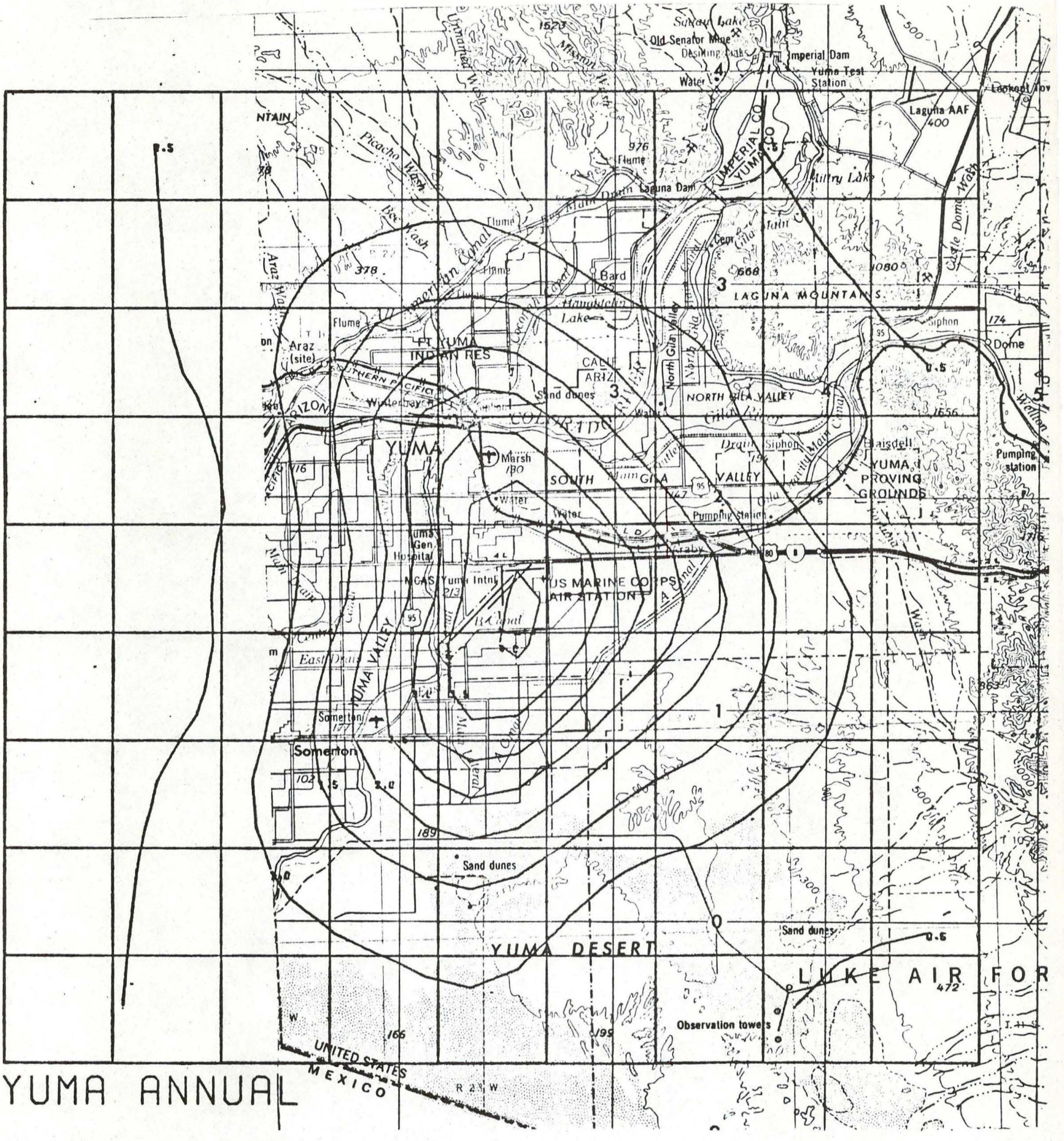

YUMA ANNUAL
YUMA
YUMA DESERT
LAGUNA MOUNTAINS
NORTH GILA VALLEY
SOUTH GILA VALLEY
YUMA VALLEY
US MARINE CORPS AIR STATION
YUMA PROVING GROUNDS
FT YUMA INDIAN RES
Somerton
Imperial Dam
Yuma Test Station
Laguna AAF
Laguna Dam
Old Senator Mine
Sand dunes
Observation towers
UNITED STATES
MEXICO
Picacho Wash
Araz (site)
Bard
Dome
Blaisdell
Marsh
Yuma Gen. Hospital
Flume
Siphon
Pumping station

Figure A-15b

APPENDIX III

Appendix III contains the computer program and illustrations of the results for Winslow for various stack heights and atmospheric stability conditions.

```
C     INPUT PARAMETERS
C
C
C     CARD 1
C      (2F10.2,4I5)
C       DX                      GRID DISTANCE (METER)
C       BX                      RURAL OR BACKGROUND SOURCE STRENGTH
C                               (MICROGRAM PER SQUARE METER PER SEC)
C       NR                      NUMBER OF ROWS, INCLUDING AN EXTRA 4 ROWS
C                               ON TOP AND BOTTOM
C       NC                      NUMBER OF COLUMNS, INCLUDING AN EXTRA 4
C                               COLUMNS ON EITHER SIDE
C       NO                      NUMBER OF CORRECTIONS TO AREA SOURCE
C                               STRENGTHS. IF NO CORRECTIONS, PUT NO = 1
C                               IF NO AREA SOURCE, PUT NO = 0
C       NH                      NUMBER OF EFFECTIVE SOURCE HEIGHT CLASSES
C     CARD 2
C      (16I5)
C       NN                      NUMBER OF STABILITY CLASSES
C     CARD 3
C      (8F10.2)
C       RX(10)                  A IN THE EQUATION (SIGMA Z = A*X**B)
C     CARD 4
C      (8F10.2)
C       PX(10)                  B IN THE EQUATION (SIMGA Z = A*X**B)
C     CARD 6
C      (16I5)
C       ID(30)                  ROW NUMBER OF AREA SOURCE CORRECTION.
C                               IF NO CORRECTION, ID(1) = 1
C     CARD 7
C      (16I5)
C       JD(30)                  COLUMN NUMBER OF AREA SOURCE CORRECTION.
C                               IF NO CORRECTION, JD(1) = 1
C     CARD 8
C      (8F10.2)
C       ST(30)                  AREA SOURCE CORRECTION. IF NO CORRECTION,
C                               ST(1) = .0
C     CARD 9
C      (8F10.2)
C       S(30,30)                AREA SOURCE STRENGTHS (MICROGRAM PER
C                               SQUARE METER PER SEC)
C     CARD 10
C      (8F10.2)
C       H(20)                   EFFECTIVE SOURCE HEIGHTS (METER)
C     CARD 11
C      (16I5)
C       NP(20)                  NUMBER OF POINT SOURCE IN EACH SOURCE
C                               HEIGHT CLASS
C     CARD 12
C      (16I5)
C       IC(10,30)               ROW NUMBER OF POINT SOURCE. IF NO POINT
C                               SOURCE, PUT IC(1,1) = 1
C     CARD 13
C      (16I5)
C       JC(10,30)               COLUMN NUMBER OF POINT SOURCE. IF NO
C                               POINT SOURCE, PUT JC(1,1) = 1
C     CARD 14
C      (8F10.2)
C       QEC(10,30)              POINT SOURCE STRENGTH (MICROGRAM PER SEC)
C                               IF NO POINT SOURCE, PUT QEC(1,1) = .0
C     CARD 15
C      (5A6)
C       ALBL                    LOCATION AND TIME FROM WHICH DATAS WERE
C                               TAKEN
C     CARD 16
C      (I5)
C       MM                      NUMBER OF WIND VELOCITY
C     CARD 17
C      (8F10.2)
C       U(5)                    WIND VELOCITY IN METER/SEC
C     CARD 18
C      (8F10.2)
C       F(5,16)                 WIND DIRECTION FREQUENCY DISTRIBUTION,
C                               BEGINNING WITH NNE AND GOING CLOCKWISE
C     CARD 19
C      (I5)
C       NNA                     IF NNA =0, ONLY AREA SOURCE IS BEING
C                               CONSIDERED, THEREFORE MAXIMUM CONCENTRATION
C                               CALCULATION WILL BE IGNORED
C                               IF NNA = 1, DAYTIME--SUNNY
C                               IF NNA = 2, DAYTIME--CLOUDY
C                               IF NNA = 3, NIGHTTIME
C
C
C     OUTPUT PARAMETERS
C
C       F(5,16)                 AS IN INPUT PARAMETERS
C       NR                      AS IN INPUT PARAMETERS
C       NC                      AS IN INPUT PARAMETERS
C       NO                      AS IN INPUT PARAMETERS
C       NP                      AS IN INPUT PARAMETERS
C       H                       AS IN INPUT PARAMETERS
```

```
C     DX                  AS IN INPUT PARAMETERS
C     BX                  AS IN INPUT PARAMETERS
C     RX                  AS IN INPUT PARAMETERS
C     PX                  AS IN INPUT PARAMETERS
C     A(30,30)            CONCENTRATIONS(MICROGRAM/CUBIC METER) DUE
C                         TO AREA SOURCES
C     AA(30,30)           CONCENTRATIONS(MICROGRAM/CUBIC METER) DUE
C                         TO CURRENT POINT SOURCES
C     CMAXR               MAXIMUM CONCENTRATION DUE TO POINT SOURCE
C     RR                  DISTANCE AT WHICH MAXIMUM CONCENTRATION
C                         OCCURS
C     CMAXF               CONCENTRAN UNDER FUMIGATION
C     XMAX                DISTANCE AT WHICH CONCENTRATION UNDER
C                         FUMIGATION IS CONSIDERED
C     ANF                 DEGREES FROM THE NORTH GOING CLOCKWISE
C
C
C     REFERENCES
C
C     1. NOLL, KENNETH, AND DUNCAN, JOSEPH, 'INDUSTRIAL AIR
C        POLLUTION CONTROL ', ANN ARBOR SCIENCE PUBLISHERS INC.
C        ANN ARBOR, MICH., 1973
C     2. TURNER, BRUCE D.,' WORKBOOK OF ATMOSPHERIC DISPERSION
C        ESTIMATES ',ENVIRONMENTAL PROTECTION AGENCY, OFFICE OF
C        AIR PROGRAMS, RESEARCH TRIANGLE PARK, NORTH CAROLINA,
C        REVISED  1970
C
C
C
C
C
C
      DIMENSION S(30,30),FU(30,30,6),C(30,30),A(30,30),D(30,30),
     1SS(30,30),AA(30,30),IC(10,30),JC(10,30),QEC(10,30),ID(30
     2),JD(30),ST(100),RX(10),PX(10),H(20),NP(20),
     3F(6,16),U(6),AAZ(30,30,6),BA(30,30,6)
      DIMENSION ALBL(5),QE(10,30)
      DIMENSION FF(16)
   99 FORMAT(5A6)
  100 FORMAT(2F10.2,4I5)
  105 FORMAT(8F10.2)
  163 FORMAT(16I5)
      READ(5,100) DX,BX,NR,NC,NO,NH
      DDX=DX
      DO 300 I=1,NR
      DO 300 J=1,NC
  300 S(I,J)=BX
      READ(5,163) NN
      READ(5,105)  (RX(I),I=1,NN)
      READ(5,105)  (PX(I),I=1,NN)
      READ(5,163)  (ID(I),I=1,NO)
      READ(5,163)  (JD(I),I=1,NO)
      READ(5,105)  (ST(J),J=1,NO)
      JI=NC-4
      IJ=NR-4
      DO 301 I=5,IJ
  301 READ(5,105) (S(I,J),J=5,JI)
      READ(5,105)  (H(I),I=1,NH)
      READ(5,163)  (NP(I),I=1,NH)
      DO 860 I=1,NH
      NNP=NP(I)
      READ(5,163)  (IC(I,J),J=1,NNP)
      READ(5,163)  (JC(I,J),J=1,NNP)
      READ(5,105)  (QEC(I,J),J=1,NNP)
  860 CONTINUE
  444 READ(5,99,END=999) ALBL
      READ(5,104) MM
  104 FORMAT(I5)
      READ(5,105) (U(I),I=1,MM)
      DO 210 I=1,MM
  210 READ(5,106) (F(I,J),J=1,16)
  106 FORMAT(3F10.7)
      READ (5,609) NNA
  609 FORMAT(I5)
      WRITE(6,230)
  230 FORMAT('1 WIND ROSE',/////)
      DO 211 I=1,MM
  211 WRITE(6,794) (F(I,J),J=1,16)
  794 FORMAT(8F10.5,//)
      IF (NNA) 665,665,660
  660 IF (NNA-2) 662,661,662
  661 RR=((H(1)*H(1)*0.75)/(0.15*0.15*1.75))**(1./1.5)
      RX(1)=0.15
      PX(1)=0.75
      SZR=0.15*RR**0.75
      IF (UAVE-2.) 663,664,664
  663 SZ=0.33*710.**0.86
      XMAX=710.
      GO TO 662
  664 SZ=0.22*2950.**0.78
      XMAX=2950.
  662 CONTINUE
      DX=DDX
      IGX=DX/1000.
      DO 610 J=1,16
  610 FF(J)=.0
      UAVE=.0
      DO 611 I=1,MM
      DO 611 J=1,16
      UAV=U(I)*F(I,J)
      UAVE=UAVE+UAV
  611 FF(J)=FF(J)+F(I,J)/U(I)
      FMAX=.0
      DO 614 J=1,16
      FFF=FF(J)
      IF (FFF-FMAX) 612,613,613
  612 FMAX=FMAX
      NF=NF
      GO TO 614
  613 FMAX=FFF
      NF=J
  614 CONTINUE
```

```
      FMAX=FF(NF)
      IF (NNA-2) 601,620,603
  601 IF (UAVE-2.) 605,604,604
  604 IF (UAVE-5.) 606,607,607
  603 IF (UAVE-5.) 608,607,607
  605 XMAX=430.0
      RR=((H(1)*H(1)*0.91)/(0.40*0.40*1.91))**(1./1.82)
      RX(1)=0.40
      PX(1)=0.91
      SZ=0.4*XMAX**0.91
      SZR=0.4*RR**0.91
      GO TO 620
  606 XMAX=710.
      RR=((H(1)*H(1)*0.86)/(0.33*0.33*1.86))**(1./1.72)
      RX(1)=0.33
      PX(1)=0.86
      SZ=0.33*XMAX**0.86
      SZR=0.33*RR**0.86
      GO TO 620
  607 XMAX=2950.
      RR=((H(1)*H(1)*0.78)/(0.22*0.22*1.78))**(1./1.56)
      RX(1)=0.22
      PX(1)=0.78
      SZ=0.22*XMAX**0.78
      SZR=0.22*RR**0.78
      GO TO 620
  608 XMAX=5900.
      RR=((H(1)*H(1)*0.71)/(0.06*0.06*1.71))**(1./1.42)
      RX(1)=0.06
      PX(1)=0.71
      SZ=0.06*XMAX**0.71
      SZR=0.06*RR**0.71
  620 EX=EXP(-(H(1)*H(1))/(2.*SZR*SZR))
      DEN=1./(SZR*RR)
      CMAXR=2.0318*FMAX*EX*DEN*QEC(1,1)
      HI=H(1)+2.*SZ
      SYF=(H(1)/8.)+(0.06*XMAX**0.71)
      CMAXF=0.3989*QEC(1,1)/(UAVE*SYF*HI)
  665 DO 789 K=1,MM
      DO 789 I=1,9
      DO 789 J=1,9
  789 FU(I,J,K)=.0
      DO 212 K=1,MM
      E=1./U(K)
      FU(5,5,K)=E
      DO 790 I=1,4
      FU(5-I,5+I,K)=F(K,2)*E
      FU(5+I,5+I,K)=F(K,6)*E
      FU(5+I,5-I,K)=F(K,10)*E
      FU(5-I,5-I,K)=F(K,14)*E
      FU(5-I,5,K)=F(K,16)*E
      FU(5,5+I,K)=F(K,4)*E
      FU(5+I,5,K)=F(K,8)*E
  790 FU(5,5-I,K)=F(K,12)*E
      FU (4,5,K)=FU(4,5,K)+E*(F(K,1)+F(K,15))
      FU(5,6,K)=FU(5,6,K)+E*(F(K,3)+F(K,5))
      FU(6,5,K)=FU(6,5,K)+E*(F(K,7)+F(K,9))
      FU(5,4,K)=FU(5,4,K)+E*(F(K,11)+F(K,13))
      DO 791 I=1,2
      FU(1+I,6,K)=F(K,1)*E
      FU(4,6+I,K)=F(K,3)*E
      FU(6,6+I,K)=F(K,5)*E
      FU(6+I,6,K)=F(K,7)*E
      FU(6+I,4,K)=F(K,9)*E
      FU(6,1+I,K)=F(K,11)*E
      FU(4,1+I,K)=F(K,13)*E
  791 FU(1+I,4,K)=F(K,15)*E
      FU(1,7,K)=F(K,1)*E
      FU(3,9,K)=F(K,3)*E
      FU(7,9,K)=F(K,5)*E
      FU(9,7,K)=F(K,7)*E
      FU(9,3,K)=F(K,9)*E
      FU(7,1,K)=F(K,11)*E
      FU(3,1,K)=F(K,13)*E
  212 FU(1,3,K)=F(K,15)*E
      WRITE(6,470) NR,NC,NO,NH
  470 FORMAT(2X,8HNO. ROWS=,I5,3X,12HNO. COLUMNS=,I5,3X,3HNO=,I5,3X,21HN
     1O EFFECT SOURCE HTS=,I5)
      WRITE(6,10) DX,BX
   10 FORMAT(2X,9HDX IN M =,F6.0,3X,23HRURAL SOURCE STRENGTHS=,F6.2,/)
      WRITE(6,12) (U(I),I=1,MM)
   12 FORMAT(2X,20HWIND SPEED IN M/SEC=,/,2X,5F10.2,//)
      DO 600 I=1,NR
      DO 600 J=1,NC
  600 QE(I,J)=.0
      DO 167 K=1,NO
      I=ID(K)
      J=JD(K)
  167 S(I,J)=ST(K)
  200 FORMAT(10F10.2)
      WRITE(6,200) ((S(I,J),J=1,NC),I=1,NR)
      DO 162 II=1,NN
      R=RX(II)
      B=PX(II)
      WRITE(6,119) R,B
  119 FORMAT(2X,43HNEW SET OF POWER LAW PARAMETERS FOR SIGMA Z,/,3X,2HR=
     1,F5.3,3X,2HB=,F5.3)
      IF (NO) 160,160,150
  150 CONTINUE
      DO 1 I=1,9
      DO 1 J=1,9
    1 C(I,J)=.0
      DO 217 I=5,IJ
      DO 217 J=5,JI
  217 A(I,J)=.0
      DO 216 K=1,MM
      BB=((DY/2.)**(1.-B))/(R*(1.-B))
      CC=9.**(1.-B)-7.**(1.-B)
      DD=.80*BB*CC
      DO 2 J=1,9,2
      C(1,J)=DD*FU(1,J,K)
    2 C(9,J)=DD*FU(9,J,K)
```

```
      DO 3 I=3,7,2
      C(I,1)=DD*FU(I,1,K)
    3 C(I,9)=DD*FU(I,9,K)
      CC=7.**(1.-B)-5.**(1.-B)
      DD=.80*BB*CC
      C(8,8)=DD*FU(8,8,K)
      C(2,2)=DD*FU(2,2,K)
      C(2,8)=DD*FU(2,8,K)
      C(8,2)=DD*FU(8,2,K)
      DO 4 J=4,6
      C(2,J)=DD*FU(2,J,K)
    4 C(8,J)=DD*FU(8,J,K)
      DO 5 I=4,6
      C(I,2)=DD*FU(I,2,K)
    5 C(I,8)=DD*FU(I,8,K)
      CC=5.**(1.-B)-3.**(1.-B)
      DD=.80*BB*CC
      DO 6 J=3,7
      C(3,J)=DD*FU(3,J,K)
    6 C(7,J)=DD*FU(7,J,K)
      DO 7 I=4,6
      C(I,3)=DD*FU(I,3,K)
    7 C(I,7)=DD*FU(I,7,K)
      CC=3.**(1.-B)-1.
      DD=.80*BB*CC
      DO 8 J=4,6
      C(4,J)=DD*FU(4,J,K)
    8 C(6,J)=DD*FU(6,J,K)
      C(5,4)=DD*FU(5,4,K)
      C(5,6)=DD*FU(5,6,K)
      C(5,5)=.80*BB*FU(5,5,K)
      DO 500 I=5,IJ
      DO 500 J=5,JI
      BA(I,J,K)=.0
      DO 500 KK=1,9
      DO 500 L=1,9
  500 BA(I,J,K)=C(KK,L)*S(I-5+KK,J-5+L)+BA(I,J,K)
      DO 501 I=5,IJ
      DO 501 J=5,JI
  501 A(I,J)=BA(I,J,K)+A(I,J)
  216 CONTINUE
  102 FORMAT('1'5A6,'  GRID DIMENSIONS ',I3,'  KM',//)
      WRITE(6,102)ALBL,IGX
   95 FORMAT('  CONCENTRATIONS FROM GROUND SOURCES',///)
      WRITE(6,95)
      DO 703 I=5,IJ
  703 WRITE(6,701) (A(I,J),J=5,JI)
  701 FORMAT(' ',9F12.2,////)
  700 FORMAT(8F10.4)
  160 IF (GEC(1,1)) 162,162,161
  161 CONTINUE
      WRITE(6,202)
  202 FORMAT('1 ELEVATED SOURCES')
      DO 899 I=5,IJ
      DO 899 J=5,JI
  899 AA(I,J)=.0
      DO 880 NI=1,NH
      DO 874 KL=1,NR
      DO 874 KM=1,NC
  874 QE(KL,KM)=.0
      WRITE(6,871) H(NI)
  871 FORMAT(2X,26HEFFECTIVE SOURCE HEIGHT = ,F10.3)
      WRITE(6,872)
  872 FORMAT(10X,7HROW NO.,3X,9HCOLUMN NO,4X,25HEMISSION(MICROGM PER SEC
     1))
      NNP=NP(NI)
      WRITE(6,873) ((IC(NI,K),JC(NI,K),GEC(NI,K)),K=1,NNP)
  873 FORMAT(2I12,F20.5)
      DO 221 K=1,MM
      DO 164 KK=1,NNP
      I=IC(NI,KK)
      J=JC(NI,KK)
  164 QE(I,J)=QEC(NI,KK)
      DO 81 L=1,9
      DO 81 KK=1,9
   81 D(L,KK)=.0
      XY=H(NI)**2./2.
      WQ=-XY/(R**2.)
      WP=(DX/2.)**(2.*B)
      P=1.*EXP(WQ/WP)
      PA=R*((DX/2.)**(B+1.))
      XINT=.0
      DDR=.0
      XX2=DX/2.
      DO 948 IJJ=1,100
      IF(IJJ-10) 952,952,953
  952 DR=100.
      GO TO 954
  953 DR=1000.
  954 DDDR=DDR+DR/2.
      DDR=DDR+DR
      XYZ=XY/(R**2.*(DDDR**(2.*B)))
      IF(XYZ-20.) 960,960,961
  960 XINT=XINT+DR*EXP(-XYZ)/(DDDR**B)
  961 CONTINUE
      IF (XX2-DDR) 955,955,948
  955 GO TO 348
  948 CONTINUE
  348 D(5,5)=XINT/(8.*R*XX2**2.)
      DO 71 L=1,4
      E=2.*L
      EF=E**(2.*B)
      XF=1.4*E
      FE=XF**(2.*B)
      Z=P**(1./EF)/(PA*(E**(B+1.)))
      IF(L-1) 950,950,949
  949 D(5,5+L)=Z
      D(5,5-L)=Z
      D(5+L,5)=Z
      D(5-L,5)=Z
      GO TO 951
  950 D(5,6)=Z/3.
```

```
      D(5,4)=Z/3.
      D(6,5)=Z/3.
      D(4,5)=Z/3.
  951 Z=P**(1./FE)/(PA*(XF**(B+1.)))
      D(5+L,5+L)=Z
      D(5-L,5+L)=Z
      D(5+L,5-L)=Z
   71 D(5-L,5-L)=Z
      DO 72 L=1,2
      QQ=2*L+2
      QG=1.1*QQ
      G=QG**(2.*B)
      Z=P**(1./G)/(PA*(QG**(B+1.)))
      D(4-L,6)=Z
      D(4-L,4)=Z
      D(6+L,4)=Z
      D(6+L,6)=Z
      D(4,4-L)=Z
      D(6,4-L)=Z
      D(4,6+L)=Z
   72 D(6,6+L)=Z
      Z=P**(.125**(2.*B))/(PA*(8.**(B+1.)))
      D(1,3)=Z
      D(1,7)=Z
      D(3,1)=Z
      D(3,9)=Z
      D(7,1)=Z
      D(7,9)=Z
      D(9,3)=Z
      D(9,7)=Z
      DO 91 KK=1,9
      DO 91 L=1,9
   91 SS(KK,L)=2.04*D(KK,L)*FU(KK,L,K)
      DO 510 I=5,IJ
      DO 510 J=5,JI
      AAZ(I,J,K)=.0
      DO 410 KK=1,9
      DO 410 L=1,9
      ADD=SS(KK,L)*QE(I-5+KK,J-5+L)
  410 AAZ(I,J,K)=AAZ(I,J,K)+ADD
  510 CONTINUE
      DO 222 I=5,IJ
      DO 222 J=5,JI
  222 AA(I,J)=AA(I,J)+AAZ(I,J,K)
  221 CONTINUE
      WRITE(6,102)ALBL,IGX
      WRITE(6,96) H(NI)
   96 FORMAT('  CONCENTRATIONS FROM ELEVATED SOURCES WITH HEIGHT = ',F10
     1.3,///)
      DO 881 I=5,IJ
  881 WRITE(6,701) (AA(I,J),J=5,JI)
  880 CONTINUE
      IF (DX-5000.) 162,622,622
  622 ANF=NF
      ANF=22.5*ANF+180.0
      IF (ANF-360.0) 670,671,672
  670 ANF=ANF
      GO TO 673
  671 ANF=.0
      GO TO 673
  672 ANF=ANF-360.0
  673 CONTINUE
      RR=RR/1000.
      XMAX=XMAX/1000.
      WRITE (6,615) UAVE
  615 FORMAT('1 AVE. WIND VELOCITY = ',3X,F12.5,3X,' METER/SEC ',/////)
      WRITE (6,616) CMAXR,RR,ANF
  616 FORMAT(' REGULAR MAXIMUM CONCENTRATION = ',3X,F12.5,3X,' MICROGRAM
     1 PER CUBIC METER ',//,2X,' OCCURS AT A DISTANCE OF ',3X,F10.5,3X
     2,'KM',4X,'AND ',3X,F6.2,' DEGREES FROM THE NORTH GOING CLOCKWISE '
     3,/////)
      IF (NNA-2) 997,998,997
  997 WRITE (6,617) CMAXF,XMAX,ANF
  617 FORMAT(' CONCENTRATION UNDER FUMIGATION = ',3X,F11.5,3X,
     1' MICROGRAM PER CUBIC METER ',//,2X,' OCCURS AT A DISTANCE OF ',
     23X,F10.5,3X,'KM',4X,'AND ',3X,F6.2,' DEGREES FROM THE NORTH GOING
     3CLOCKWISE ',/////)
  998 CONTINUE
      IF (RR-5.) 621,621,162
  621 DX=1000.
      IGX=1
      GO TO 160
  162 CONTINUE
      GO TO 444
  999 CALL EXIT
      END
```

Sample Results

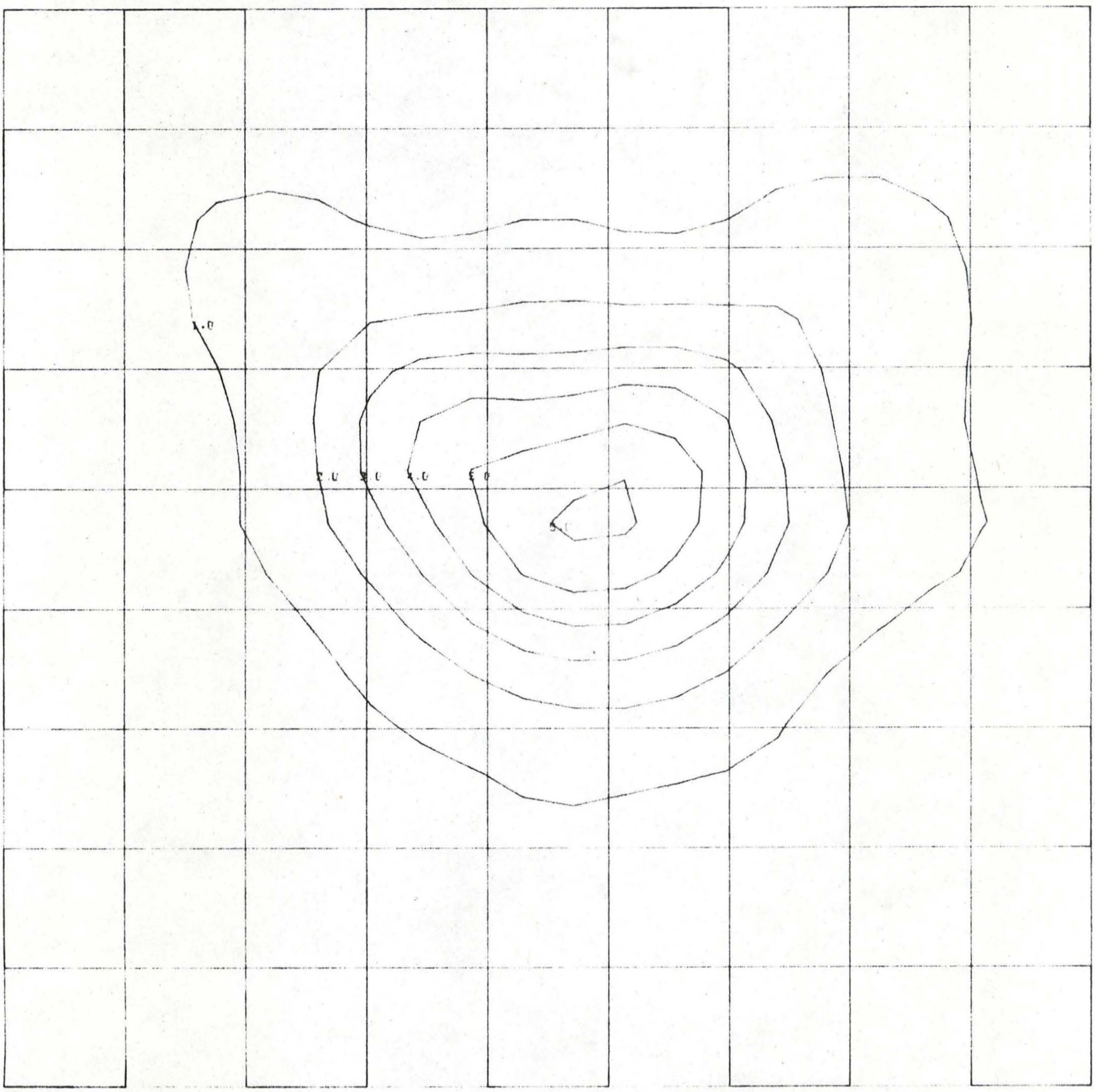
Location Winslow, Arizona

Figure	Grid Size, km	Stack height, m	Atmospheric Stability
A-16	5	50	neutral
A-17	5	50	stable
A-18	0.2	10	neutral
A-19	1	100	unstable
A-20	1	50	unstable

Parameters for σ_z for different atmospheric stability

	a	b
Stable	.06	.71
Neutral	.15	.75
Unstable	.40	.91

Figure A-16



WINSLOW ANNUAL

Figure A-17

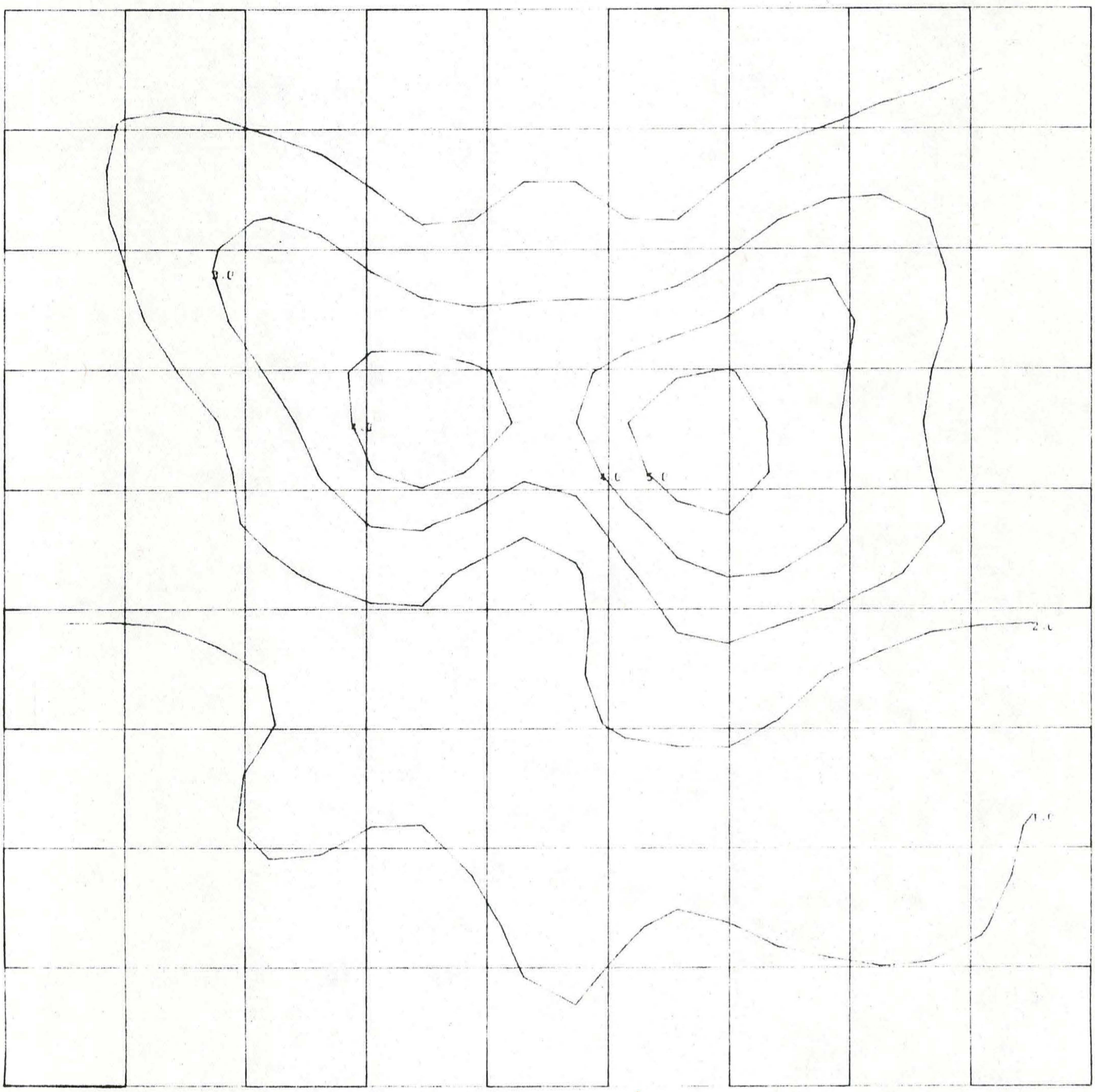


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Figure A-18

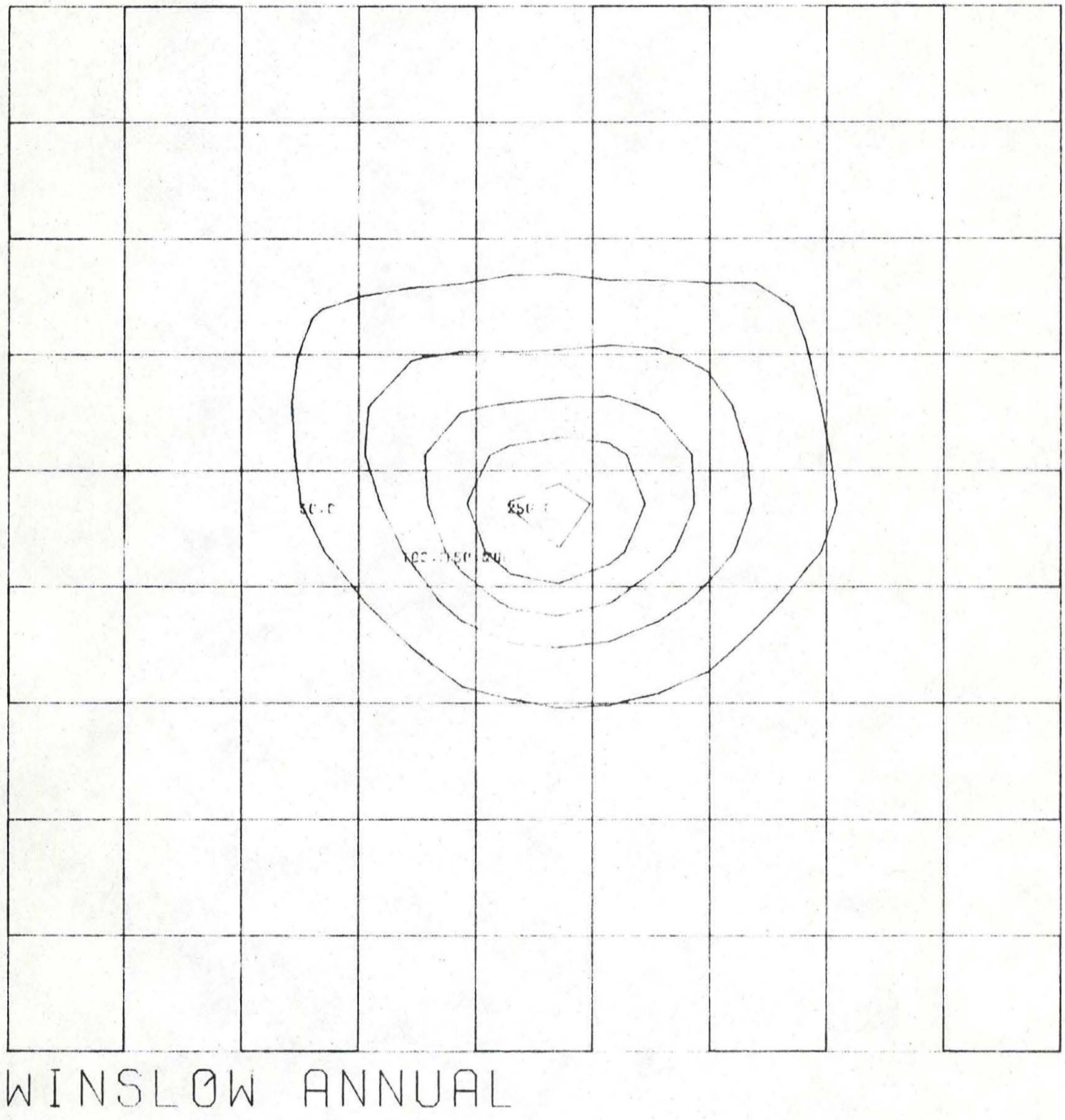


Figure A-19

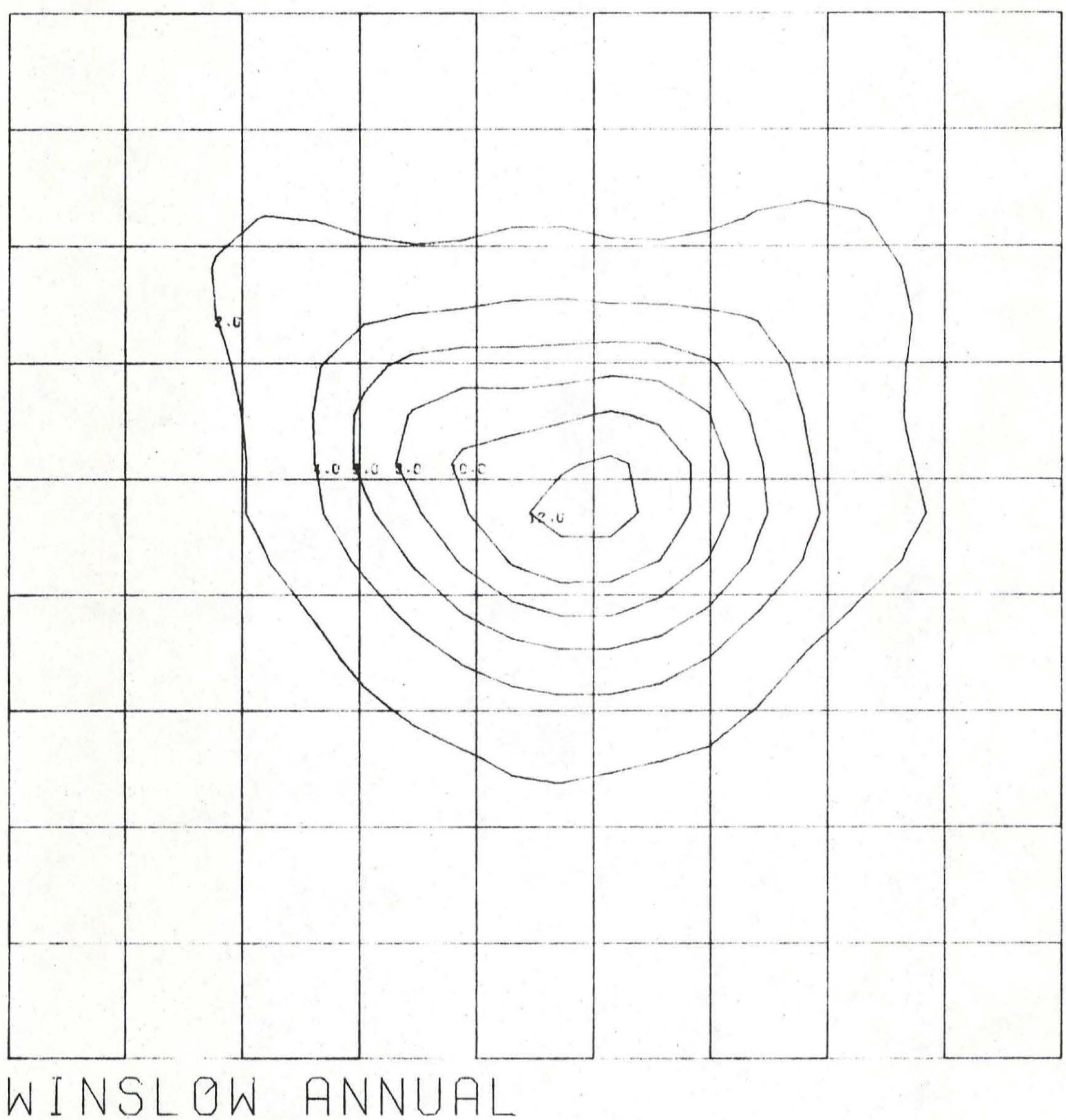
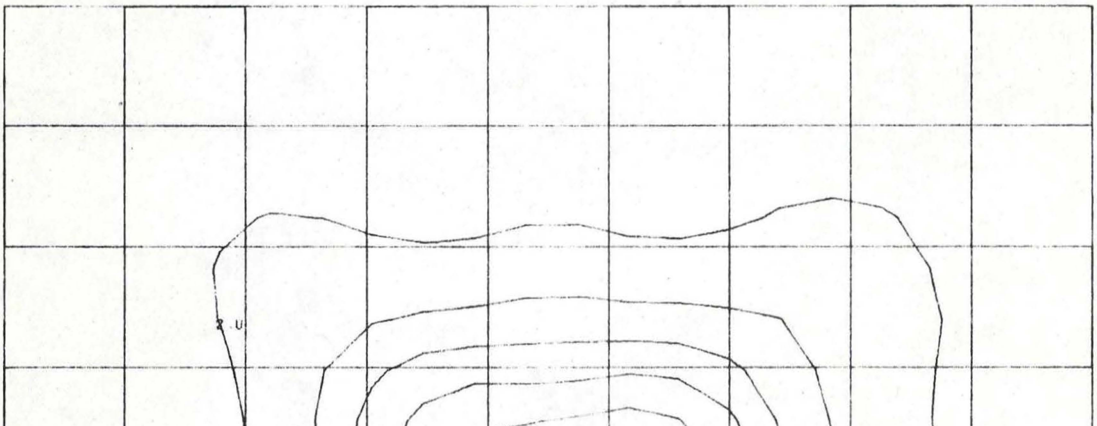


Figure A-20



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